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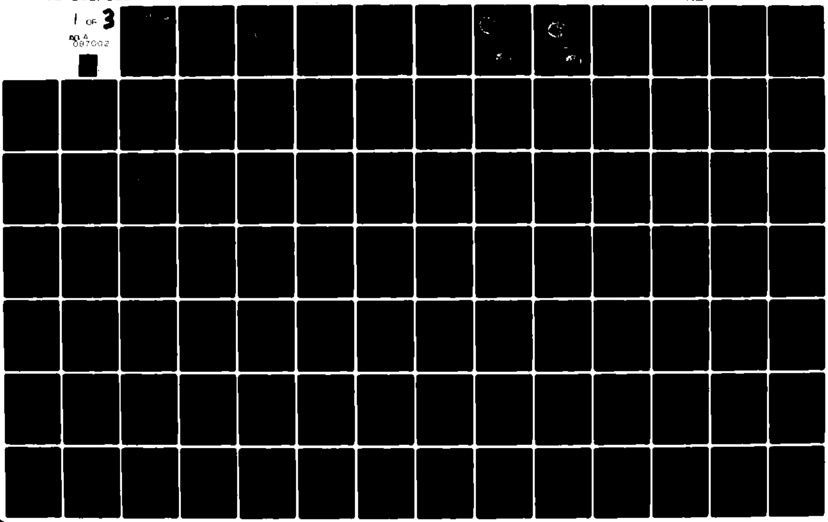

FINAL REPORT

Freshwater Mussels (Mollusca: Bivalvia: Unionidae) of the Upper Mississippi River Observations at Selected Sites within the 9-Foot Navigation Channel Project for the St. Paul District, United States Army Corps of Engineers, 1977-1979

Volume I: Text

THE ACADEMY OF NATURAL SCIENCES OF PHILADELPHIA NINETEENTH AND PARKWAY PHILADELPHIA PA 19103

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10 Samuel L. H. Fuller

Report No. 79-24F

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Academy of Natural Sciences of Philadelphia

Division of Limnology and Ecology

19th and the Parkway Philadelphia, PA 19103

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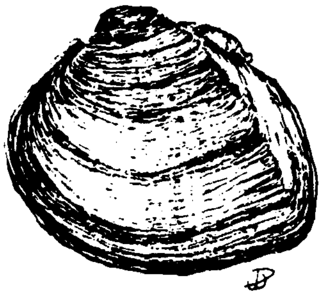

Deertoe

Truncilla truncata (Rafinesque)

REPORT ORGANIZATION AND AVAILABILITY

Report Organization

Under United States Army Corps of Engineers Contract No. DACW 37-78-C-0133, this report is issued in two volumes: Volume I, Text, and Volume II, Appendices. Several sections are included in both parts: Title Page; Report Organization and Availability (the present section); Table of Contents; Correlation of Rivers, Pools, and Sites with Exhibits; and Additions and Corrections. Several other sections occur only in Volume I: Bibliography, Glossary, and Index. The Bibliography covers the entire report; the other two sections, Volume I only. The Glossary is essentially restricted to Volume I because the terminology used only in Appendix E is defined in its introduction.

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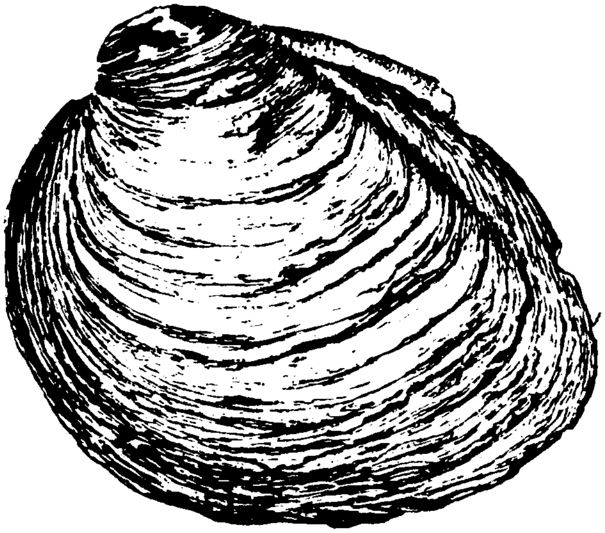
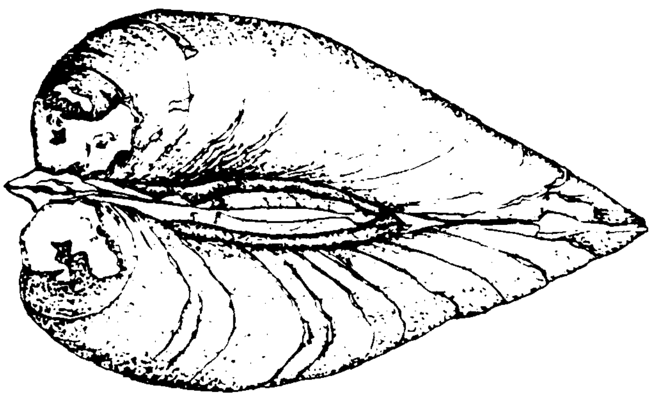


Pleurobema
rubrum
(Rafinesque)

Pink Pigtoe



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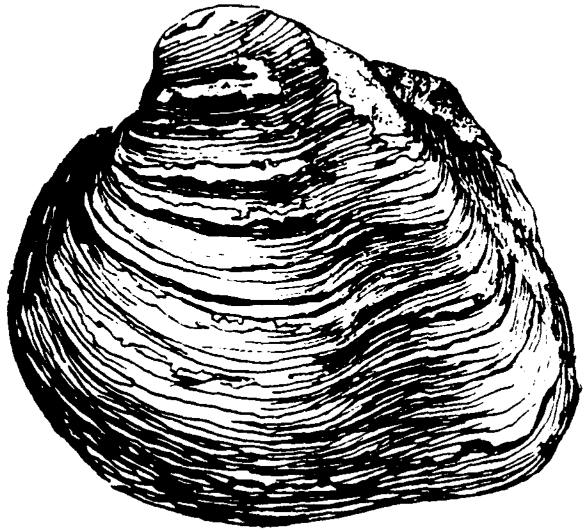
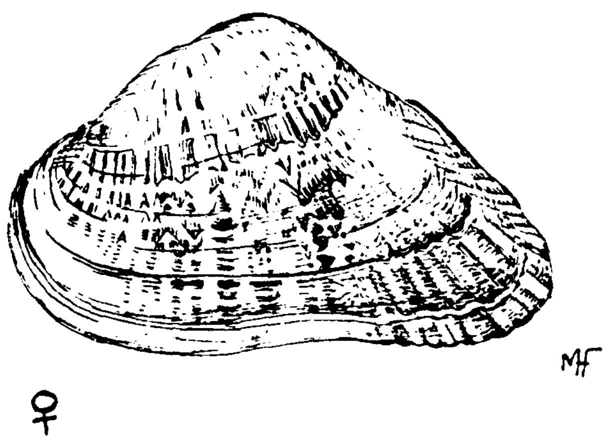


Fusconaia flava (Rafinesque)

Pigtoe



Snuffbox

Plagiola triquetra (Rafinesque)

ABSTRACT

From 1977 through 1979 the Academy of Natural Sciences of Philadelphia studied Upper Mississippi River (UMR) drainage freshwater mussels (Mollusca: Bivalvia: Unionidae) for the St. Paul District, Army Corps of Engineers. The primary objectives of the study were to characterize the present mussel fauna, to compare it to the fauna existing before the 9-Foot Navigation Channel Project, and to determine the influence(s) upon mussels by practices of the District's Operations and Maintenance (O & M) activities.

The study area was the main channel and main channel borders of the UMR itself from Head of Navigation at river mile (RM) 857.8 in the Twin Cities, Minnesota, to Locks and Dam 10 at Guttenberg, Iowa (RM 615.1), and the lowermost (Corps-maintained) reaches of the Black (at La Crosse, Wisconsin), Minnesota, and St. Croix rivers. More than 100 formal Sites were thoroughly surveyed (usually by brailing), and about a dozen locations were investigated cursorily. Over 10,000 living mussels were collected and examined, including a few of the Endangered *Lampsilis higginsi*.

For each Site, mussels found are described and an assessment is made of the impact, if any, of O & M activities upon mussels. Discussions are also included of (1) the history and present condition of several UMR mussel taxa; (2) habitat requirements of UMR mussels; (3) the 9-Foot Channel Project's impact upon the mussel fauna; and (4) recommendations for enhancement of the mussel resource through O & M practices. The appendices include Site-specific mapping and sampling data and an illustrated key to Recent UMR species-group mussel taxa.

Among numerous conclusions reached during this study are the following:

1. Qualitatively new conditions for mussels were created by the 9-Foot Channel Project's impoundment of significant stretches of the UMR. This introduced new problems for mussels, notably reduction of the movements of fishes that host parasitic mussel larvae and acceleration of sediment accumulation.

2. The Corps' perpetuation of impoundment to facilitate commercial navigation results in great stabilization of water levels but requires recurrent dredging of the main channel. The former is to mussels' advantage, and the only serious disadvantage for them in channel-maintenance dredging has been improper disposal of dredged materials, especially in backwaters.

3. Efforts should be concentrated on preventing sediments from entering the river and on more careful disposal of dredged material. For example, bank repair on the Chippewa River is advisable.

4. Fishways should be considered for installation at locks and dams. The dependence of mussels upon fish is emphasized by the conclusion that glochidial hosts are the only consistently observed partitions among mussel species' habitats.

5. The extent to which mussels have been adversely affected by the Project and its associated O & M activities has been minor in comparison to two extrinsic factors: commercial mussel harvest and degraded water quality, the latter caused principally by municipal and industrial wastes and by biocides in agricultural runoff.

6. The UMR drainage mussel fauna is in decline, but many species still reproduce successfully. Thus there is potential for a continuing ecosystematic mussel resource if water quality improves. The Corps can take some actions to ameliorate sedimentation problems, but water quality regulation is largely beyond its jurisdiction. The help of other government agencies and the private sector is required.

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INTRODUCTION

At the request of the St. Paul District, United States Army Corps of Engineers, The Division of Limnology and Ecology of The Academy of Natural Sciences of Philadelphia has conducted a three-year study of freshwater mussels (Mollusca: Bivalvia: Unionidae) in the portion of the 9-Foot Navigation Channel Project within the St. Paul District.

The Corps is charged (by the United States Congress) with maintaining the 9-Foot Navigation Channel in the Upper Mississippi River (UMR) and some of its tributaries. The required maintenance activities are of several kinds, two of which are pertinent to the Academy's investigations: "bank repair" (shoreline stabilization in order to reduce erosion) and dredging. The latter activity is especially extensive and intensive, because of the rapid accumulation of eroded sediments in the channel. Of the two activities, dredging is much more likely to jeopardize macrobenthos, including mussels, and thus has been the primary focus of the Academy's inquiry. Nevertheless, numerous locations of proposed bank repair are considered in this report.

As plentifully demonstrated by historical and modern scientific records and by the existence of a commercial fishery for much of the last century, there has been a well established community of freshwater mussels in the UMR. The increasing rarity of many of these animals was officially recognized in 1976, when, under the provisions of Public Law 93-205 ("The Endangered Species Act of 1973"), the Department of the Interior declared "Endangered" certain mussels that have been recorded from the UMR (see Discussion: Species-Group Mussel Taxa, below). Furthermore, Section 7 of that Act stipulates federal interagency cooperation to protect such species. Accordingly, the St. Paul District authorized the Academy's 1977 through 1979 study to determine the influence of its Operations and Maintenance (O & M) activities upon the 9-Foot Channel mussel fauna within the St. Paul District.

The present document reports results and interpretations of the 1978 and 1979 field work and reviews certain aspects of the study in 1977 [which has already been reported by Fuller (1978b)]. Project design was developed through coordination among the Corps, the United States Fish and Wildlife Service, the Wisconsin Department of Natural Resources, and the Academy.

The area considered in this report consists of navigable waters (and associated backwaters) in the lower Minnesota, Black, St. Croix, and Upper Mississippi rivers. Over 100 Sites were examined. Sites were chosen for study because they had an extensive dredging history, were scheduled for O & M activities, and/or were known or inferred to harbor Endangered Species of mussels.

At each Site, the mussel community was sampled, and various observations were made in regard to the physical and biological conditions of the Site, the status of the mussel community, and the possible effects of channel-maintenance and other O & M activities on this community.

A literature search was conducted to document historical presence/absence records of mussels within the study area. Comparison of the historical record with the Academy's 1977 through 1979 observations in the field permits assessment of the decline of UMR mussels, including possible adverse impact by Corps channel-maintenance dredging and other O & M activities. The Bibliography includes references cited in this report, plus any relevant sources that have come to the Principal Investigator's attention since preparation of the Academy's initial mussel report to the Corps (i.e., Fuller, 1978b).

The appendices present the following information:

- Appendix A is a complete systematic list of scientific and common names of UMR species-group mussel taxa and their host fishes.

- Appendix B presents the data describing the collecting effort at each Site.

- Appendix C compares the presence/absence mussel data of this study to historical records.

- Appendix D provides maps of the study area on which are indicated St. Paul District Pools and Sites that were studied by the Academy.

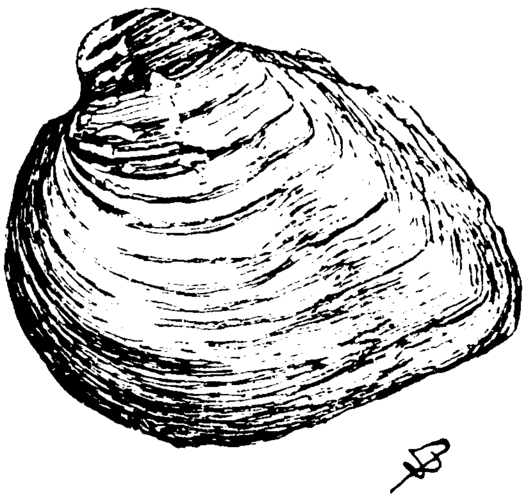
- Appendix E is an illustrated key to taxonomic identification of mussel species (and subspecies) that have been recorded alive from the UMR.

The Academy's report on its 1977 field work and 1977-1978 literature search (Fuller, 1978b) discussed Sites in the Corps' St. Paul and Rock Island Districts. However, the latter District did not participate in this project during 1978 and 1979, and Rock Island District data are not presented in the present document.

All information about Nearctic unionid glochidial hosts then known to the Principal Investigator was provided in the previous report (see Fuller, 1978b: Appendix D). This body of information (Fuller, 1974, 1978b) is not reproduced in the present document, but some of these data, plus new ones, are discussed below (see Discussion: Species-Group Mussel Taxa).

Although considerable attention was directed toward identifying habitat parameters of critical importance to mussels, time limitations precluded detailed site descriptions in every instance for all parameters. As noted by Fuller (1978b) in regard to the 1977 field work,

> The important role of aquatic vegetation in mussel biology is occasionally addressed in the accounts of Sites and taxa in the text. However, no extensive data were recorded, largely because of the late start of the field work and the increasing senescence of the vegetation as the season progressed.
>
> Similarly, attempts to record precise water depth measurements were abandoned after it became evident that changing river stages meant that such data provided an invalid basis for comparisons between and among Sites and/or taxa. However, the issue of depth is addressed in general terms in many of the natural histories below (see Discussion: Species-Group Mussel Taxa).



Pigtoe

Fusconaia flava (Rafinesque)

METHODOLOGY

The field study was conducted from mid-July through mid-November 1977, mid-July through late October 1978, and June through early July 1979. The crew usually consisted of three men, who were joined for varying lengths of time by several other workers and numerous observers. The R/V IZAAK WALTON, a 55-ft houseboat fitted out as a research vessel (R/V), served as a houseboat and field laboratory. Mussels usually were collected from a 16- or 18-ft johnboat equipped with a 25- or 35-hp Evinrude outboard motor.

The area studied in the field consisted of Sites of O & M activity in those portions of three rivers in the UMR drainage that are within the 9-Foot Navigation Channel Project and the Corps St. Paul District. These three rivers are the UMR itself, and the lowermost (Corps-maintained) portions of the Minnesota River (which enters the Mississippi in Pool 2) and the St. Croix River (entering in Pool 3). The relevant portion of the UMR extends from Locks and Dam 10 (RM 615.1), Guttenberg, Iowa, northward and upstream to the head of navigation at the SOO Line RR bridge (RM 857.8) in Minneapolis, Minnesota. No sampling occurred in the Black River (which enters the UMR in Pool 8), but relevant data from another study (Havlik, 1978a) are given.

Study sites were defined for 1977 collections by Fuller (1978b) as follows:

> Unless otherwise specified by the Corps, the areal limits of a given Site consisted of both an Impact Zone and the one-mile reach immediately below it. The Impact Zone was the reach that included all potential dredge cuts and placement sites for dredged riverbed material. The Impact Zone's upper river mileage was that of the upper terminus of the uppermost dredge cut or placement site; its lower limit was the river mileage of the lower terminus of the lowermost dredge cut or placement site. Intensive sampling was conducted in the Impact Zone and for a 1/4-mile reach below it, because of the possibility that material disturbed during dredging might migrate that far. Cursory sampling was stipulated for an additional 3/4-mile reach immediately downstream, but sampling in that reach was always intensive if the mussel fauna there was well-developed.

The definition was changed for the field work in 1978 and 1979. This redefinition was enabled chiefly by Marking's and Bill's (1977) finding that mussels' burial in sediment is less harmful than other workers had thought. Because the threat to mussels posed by sediment migration during dredging is less than had been supposed, the 3/4-mi reach below a Site was eliminated. However, the Principal Investigator was permitted to continue surveillance through this reach and beyond if warranted by the prosperity of the relevant Site's mussel community. Because the UMR mussel fauna in the St. Paul District is in general not prosperous, such Sites were rare.

Within a given Site, the Academy's team surveyed the mussel community in locations that were potentially subject to direct and/or indirect impact from O & M activities, notably channel-maintenance dredging. As indicated by Fuller (1978b), "Such locations usually consisted of the main channel, main channel borders, and (any) major side channels".

Brailing was the most important method used to collect mussels (in water depths up to about 30 ft). In terms of design, efficiency, and environmental damage, the brail is a controversial device (see, e.g., Coker, 1919, and Krumholz et al., 1970), but it was used because it maximizes the amount of mussel presence/absence data that can be obtained in a given time, while causing minor mussel mortality.

Trailing the brail from its bow, the johnboat was backed slowly downstream. The collecting gear's towrope was thus kept clear of the outboard motor's propeller, and transmission of the motor's vibration through the rope to the brail was minimized. Five-minute "brail runs" were generally used; at the end of a run, the brail was raised and any captured mussels were detached from it.

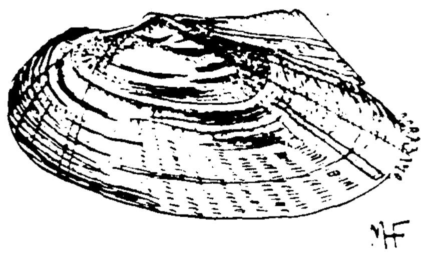
Other sampling techniques were employed when appropriate. In very shallow waters (up to about three feet in depth) mussels were "pollywogged"; in pollywogging the wading or swimming collector secures mussels by hand. A Needham scraper was sometimes used in very slightly deeper waters; this tool is a wire-mesh basket (with a flanged lip) that is attached to a lengthy handle and is used like a rake. These exclusively shallow-water techniques were used primarily in the hope of securing juvenile mussels to enhance understanding of local population structures; productive shallows were rare or non-existent at most Sites.

When this project began, it was believed that diving would be essential to the field work, especially in respect to legally protected mussels (e.g., those listed as nationally Threatened or Endangered Species). Consequently, the Academy team included biologists who were certified SCUBA divers, and the R/V IZAAK WALTON was equipped with SCUBA gear and HOOKAH hard-hat apparatus. The need for these preparations was minimal because legally protected species were so rarely encountered. Nevertheless, restoring such individuals *into* their original streambed (see Imlay, 1972b) was possible because of diving capability.

After collection, mussels were transported to the field laboratory by means designed to minimize trauma, such as thermal shock, that can interfere with the animals' normal biological functions.

Mussels were processed daily aboard the IZAAK WALTON. They first were opened and searched for evidence of disease such as mites or other parasites. Tissue samples commonly were removed

and frozen for subsequent biochemical analysis at the Academy (this type of research is reflected in the classification employed in Appendix A). The shells were cleaned of remaining tissue and identified in the field. Some individuals were preserved whole to maintain in lifelike aspect certain soft-tissue features that are important in taxonomic identification. Such preserved material also was essential to creation of several of the figures used to illustrate the taxonomic key in Appendix E. All specimens were shipped to the Academy for Electronic Data Processing (EDP) and cataloging into the collections of the Department of Malacology.



Fragile Papershell

Leptodea fragilis (Rafinesque)

RESULTS: SITES

During the period 1977 through 1979, the Academy conducted definitive mussel surveillance at 100 Sites in the St. Paul District in accordance with stipulations of this project's 1977 and 1978 Scopes of Work (discussed in Methodology). In addition, either definitive or cursory surveillance of a number of other, sometimes lesser sites was carried out (Fuller, 1977, 1978a, 1979c); most of this work was accomplished with the help of the WDNR mussel survey team for the year in question. Reports on these auxiliary sites and on Sites definitively surveyed in 1977 are not formally part of the present (1978 and 1979) project. Nevertheless, in the interest of a complete portrayal of the Academy's work in the St. Paul District since 1977, all sites (large or small, definitive or cursory) are reviewed in the accounts that follow.

In these accounts are extensive quotations from Fuller (1978b), where the 1977 definitive Sites were first discussed. Some of the quotations are complemented with new information. The new information sometimes is about mussels, but most often concerns dredging conducted since the time of the most recent dredging reported in the St. Paul District 1974 Environmental Impact Statement (USACE, 1974b). Dredging data for recent years were supplied by the Corps. The source of these data is provided here rather than at each mention in the text.

By far the majority of the areas surveyed are historical, current, and/or prospective channel-maintenance dredging sites. For most of these there exists a clear, Corps-documented history of dredging activities. These activities range from almost perennial, often very heavy dredging to infrequent dredging of small quantities of material. A smaller number of Sites concern small boat and/or commercial harbors, for which Corps dredging records seem to be less thorough; other relevant recent records, however, seem nearly complete. A very small number of Sites are locations of proposed construction; with few exceptions, these have little or no history of dredging.

Minnesota River (Exhibits 2, 91, 197, 207)

1. Below Cargill (Exhibits 2, 91, 197, 207)

2. Petersons Bar (Exhibits 2, 91, 197, 207)

3. Route I-35W Bridge (Exhibits 2, 9, 197, 207)

As reported earlier (Fuller, 1978b):

The three Sites are discussed as a unit because of their contiguity and environmental similarity.

The Corps has conducted very little channel maintenance dredging in the Minnesota River, most of it occurring during the last decade. Dredging has been both infrequent and very localized, restricted to six areas, two of which are within the reach surveyed by the Academy. This history (USACE, 1974b), however, cannot have been very important to mussels -- and certainly is not now -- because the fauna has been devastated, as discussed below.

Mussels probably are extinct in the lower Minnesota River and have been so for many years. Not even recently dead gapers were found; all observed material was long dead or subfossil. To what extent these phenomena pertain throughout the river is uncertain because the upper Minnesota has not been thoroughly examined of late years, but they definitely pertain from Port Cargill to confluence with the Mississippi. This entire reach was brailed wherever gravel bars were suspected because of nearby gravel riverbanks.

It is clear that this river once supported a strong naiad fauna. From Dawley's (1947) lists of Minnesota drainage mussels can be inferred 32 presently acceptable species-group taxa. At the Sites the Academy investigators observed many of these, often so abundant that the banks consisted almost entirely of shell.

The probable cause of this destruction is agricultural runoff. Very heavy organic enrichment, emanating from manure and other fertilizers, is doubtless responsible for the benthic filamentous green algae that sometimes became entwined in the brail and for the miles-long blooms of diatoms and bluegreen algae observed at water's edge. Organic loading, however, is probably not wholly responsible for the naiad extirpation. Biocides are suspected as a complementary agent.

Regardless of the identities of the lethal factors, they seem to continue at levels sufficiently high to prohibit recolonization from refugial populations higher up the Minnesota sub-basin, such as the extant (though damaged) fauna in the Blue Earth River (see Chelberg, 1974, 1978). This means that the Minnesota River, acting as a point source where it enters the Mississippi in upper Pool 2, must exert a powerful adverse influence. Pollutants from this source, plus the Twin Cities' contributions, continue to damage mussels, in at least Pools 2 and 3.

Since this excerpt was written, Bereza (1978) surveyed the mussel fauna of the Minnesota and Blue Earth Rivers in the middle Minnesota River drainage at and near Mankato, Minnesota, on behalf of the St. Paul District. More recently, National Biocentric (1979a,b,c,d) surveyed the naiades of the upper Minnesota River proper. These efforts revealed a Minnesota River mussel fauna that is substantially impoverished compared to Dawley's (1947) historical records. The "refugial populations higher up the Minnesota sub-basin" that are, in effect, postulated in the quotation above will probably continue to be unable to recolonize the navigable Minnesota River downstream. Mussels are nearly extirpated in Pool 2, to which the Minnesota is tributary, so no naiad recruitment to the Minnesota from the UMR is likely. The outlook for the historically rich mussel fauna of the Minnesota River drainage is very poor, both within and without the reach where navigation is supported by Corps channel-maintenance dredging.

St. Croix River (Exhibits 92, 199)

Surveillance of all areas in the St. Croix River where the Corps has ever dredged (USACE, 1974b) was completed in 1978, whereas work at Hudson only had been accomplished in 1977 (Fuller, 1978b).

Some new information has been gained, of course, but it has not greatly changed the apparent composition of the St. Croix mussel fauna (compare Exhibit 92 to Exhibit 51 in Fuller, 1978b). One point *is* newly evident, however: the Hudson mussel bed probably is the last one remaining in this river, which was once rich in mussels.

It is now unfortunately clear that the evaluation of the St. Croix River mussel fauna in Fuller (1978b) is overly optimistic. In navigable waters, at least, the river's fauna is in danger of extirpation. This prognosis is not altered by Williams' (1978) recent records of living mussels in the St. Croix, even though they add some species to Dawley's (1947) list (see Exhibit 92).

4. Stillwater (Exhibits 3, 93, 199, 208)

A very large quantity of material was removed in 1945, but the Corps never dredged here again (USACE, 1974b). Any damage to mussels caused by that work should by now have been followed by substantial recovery, but even beyond the original dredge cut very few living mussels were found. This is all the more surprising because this Site exhibits extensive shallows and vascular vegetation, which commonly form

excellent nursery habitat elsewhere in the study area. If wastes from the town of Stillwater were sufficient to account for the sparse mussel population here, their effects should be in evidence at least as far downstream as the Hudson Railroad Bridge Site. Apparently they are not, however, for the Hudson mussel community is very good. The only other apparent explanation of the disappointing Stillwater naiad fauna is the evidence of trematodiasis observed at the Hudson Site (see below).

The samples at the Stillwater Site were dominated by Pigtoe, *Fusconaia flava*, which often is a common species in disturbed environments. One living Paper Floater, *Anodonta imbecillis*, was taken. The Stillwater record may be the northernmost for navigable waters of the UMR drainage. The Paper Floater has been recorded in the free-flowing Mississippi above the Twin Cities (Dawley, 1947).

5. Hudson (Exhibits 4, 94, 199, 209)

As previously reported (Fuller, (1978b):

> Using Dawley's (1947) lists of mussel species of Lake St. Croix, the St. Croix River, and the St. Croix River drainage as reference points, one concludes that the Hudson Site fauna persists in excellent health as measured by both number and variety of species. Dawley's totals are 16, 25 and 29 species, respectively. This survey's total is 23, which compares favorably with any of those (each of which has been adjusted according to recent taxonomic concepts and is lower than Dawley's original figure). The 1977 total includes what appear to be three new records for the entire St. Croix drainage: *Quadrula metanevra*, *Q. quadrula*, and *Elliptio crassidens*. Also, this total increases the Lake St. Croix list by about 50%, an extraordinary advance. In terms of the variety of its naiad fauna, Lake St. Croix appears not to have declined, in spite of the present era of general environmental degradation.
>
> Most of the Academy's positive Hudson data were derived from investigations of a seam of mussels that proceeds downriver along the Minnesota shore for several hundred meters below the Hudson RR Bridge. In terms of quantity and frequency, Corps dredging in the vicinity of the Hudson Site, including the seam just mentioned, appears to have been minor, certainly in comparison to such activity elsewhere in the St. Paul District (USACE, 1974b). Indeed, the "RR bridge seam" is of such vigor that to suppose serious nearby disturbance appears unwarranted. For example, Academy brailing and HOOKAH divers discovered two *Lampsilis higginsi*, a male and a gravid female. This Endangered Species was not only surviving, but also accomplishing fertilization, the first step in reproduction, on the border of

the main channel and within a few meters of an area that has been dredged several times, most recently and extensively in 1970.

It is highly unlikely that these two animals migrated to their points of capture during the seven years since 1970. First, both individuals were far more than seven years old. Second, adult mussels do not move great distances (unless stimulated by heat, for example) and rarely move at all (see Fuller, 1974b), especially in stable riverbed (discussed below) such as that occurring below the RR bridge. Third, as discussed below, there is no other population at this Site from which the two Higgins' Eye could have migrated.

The implication is that sediment migration caused by dredging has not been a problem here. Similarly, inspection of old dredged material at this Site revealed few dead shells. It is therefore apparent that the Corps' channel maintenance activities at Hudson have had little adverse impact upon mussels....

In sharp contrast to the RR bridge population, few mussels were found elsewhere at the Hudson Site. Presumably, the type of riverbed below the bridge (extending spottily along the Minnesota shore downstream to about the federal highway 12 bridge) provides the only prime mussel habitat in the Site. Diving revealed that the riverbed here is an admixture of mud, gravel, and small stones. Because it is stable, yet penetrable by infauna, this type of substrate strongly favors exploitation by mussels (Kaskie, 1971). The extensive beds of submerged vascular vegetation just below the RR bridge provided further stability; mussels, including juveniles and young adults, were exceptionally plentiful in that muddy area. In sandy places, however, mussels were very rare, and extensive pollywogging was required in order to find the few individuals that were secured.

These observations bear out Kaskie's (1971) ranking of substrates in descending order of preference by mussels: "mud, fine gravel, gravel, sand, and sludge". Substrate approximating Kaskie's "sludge" (a combination of materials dominated by silt and find sand) was seldom encountered at the Hudson Site except in the small-boat harbors, and mussels were not found in it. H.M. Paulson (personal communication) contended that Threeridge, *Amblema plicata*, can still be found on the harbor floor at the St. Croix Marina, but the Academy was unable to corroborate this.

Although optimal habitat was limited, a diversified mussel community was present at the Hudson Site, as already intimated. As is often the case, most of the 23 species were uncommon or even very rare, and the fauna was dominated by *Amblema plicata*, whose 266 individuals comprised 48.7% of the 546 that were found. Domination by Threeridge is a pattern that was to be encountered throughout the study area. The next to the most common species was *Fusconaia flava* (13.19%), which was proportionally better represented than at

many Sites. *Elliptio dilatata* accounted for 6.78% of the material. Hudson is one of only two Sites where this species was common (Hay Point Bank Repair in Pool 10 is the other). Hudson was the only Site where *Lampsilis radiata siliquoidea* was common and one of the few where *Lasmigona complanata* (even at only 1.28%) was at all well represented.

Additional observations further evidenced the excellence of the Hudson Site naiad fauna. There were several year-classes among the juveniles recovered byssally attached to the brail and collected by hand in weed beds. Very difficult to secure by ordinary means, juveniles comprised 1.65% of the catch and represented four species. The one juvenile *Fusconaia flava* was among the few found in the entire study area. Good year-class representation among adults was common to this and other species. One readily infers that reproduction *and* recruitment occur at Hudson.

However, not all is potentially well with this community. On 8 August 1977 living *Corbicula fluminea* were discovered at the Hudson Site. This may be the first record of the Asiatic Clam in the St. Croix River drainage. The appearance of this exotic competitor for benthic space is to the disadvantage of native mussels; for example, there is evidence that *Corbicula fluminea* can dislodge mussels from the streambed, thus uprooting them to their eventual death (Fuller and Richardson, 1977). If this creature becomes established among the railroad bridge population, the Hudson Site mussel fauna will probably become greatly simplified after a few years.

Corps dredging at the Hudson Site was minor for many years (USACE, 1974b) until 1974, when a large quantity of material was removed. These activities have been concentrated just below the railroad bridge within a few meters of the mussel bed along the Minnesota shore opposite Hudson. The mussels do not seem to have been adversely affected by this nearby dredging. Perhaps this is because any riverbed material resuspended by these operations has been swept downstream by the rapid current immediately below the bridge. The bridge is built on a peninsula that extends from the Wisconsin shore almost entirely across the river and thus severely constricts the St. Croix flow. This causes the strong current at and downstream from the bridge.

Since the preceding excerpt was written, the Academy field team revisited Hudson in 1978 while other Sites on the

St. Croix were being surveyed for the first time on behalf of the Corps. Hudson was not a formal Site in 1978, but the Academy crew had several opportunities to re-examine the mussel bed immediately downstream from the railroad bridge. The Academy secured several additional mussel data in 1978, partly because the St. Croix was much lower than it had been during the field crew's visits in 1977. The new data make understanding of the composition of the Hudson fauna more accurate, but do not introduce any major changes (compare Exhibit 94 to Exhibit 52 in Fuller, 1978b).

Two important considerations *have* emerged, however, as is more fully discussed below (see discussion of Species-Group Mussel Taxa). First, the earlier identification of Elephant Ear, *Elliptio crassidens*, at Hudson (Fuller, 1978b) is now in question. The Academy's 1977 records of this species, at Hudson, are the only recent ones for the entire study area. Should they be considered to be misidentifications of the similar *E. dilatata*, one could only conclude that *E. crassidens* is probably extinct in the UMR and perhaps in its drainage.

Second, parasitism may be a threat to the mussels of the St. Croix River. Several living Higgins' Eye, *Lampsilis higginsi*, an Endangered Species, were recovered by pollywogging opposite Hudson in 1978. Most of the observed females were gravid. These records, in addition to the Academy's 1977 ones, strengthen the belief that the Hudson population of Higgins' Eye is viable. On the other hand, one of the 1978 Higgins' Eye specimens was heavily infested with a parasitic fluke (Platyhelminthes: Trematoda). This point somewhat counters the idea of this population's viability.

Partially reviewed by Fuller (1974), Nearctic trematode flukes that infest mussels include few species, one of which is *Aspidogaster conchicola* Von Baer. Williams (1978) reported this species from mussels collected at Hudson in 1977, the year of the Academy's first visit on behalf of the Corps. However, Williams reported no pathology caused by *A. conchicola*. On the other hand, he apparently examined no living *Lampsilis higginsi*. Correlation of mussel diseases with pathogenic flukes is difficult (Seitner, 1951). Coil (1953) described a fluke that appears to exhibit host-specificity at the generic level, i.e., with regard to *Lampsilis*. It is germane to note that encystment by flukes was noticed at Hudson in the viscera *and* mantle margin of Higgins' Eye, as well as in other *Lampsilis*, *L. radiata siliquoidea* (Fat Mucket) and *L. ovata ventricosa* (Pocketbook).

The question of disease (in Higgins' Eye and other mussels) that may be caused by flukes at the Hudson Site and elsewhere in the study area requires further study.

Williams' (1978) work is additionally of value because he recorded at Hudson two mussel species that were not detected by the Academy: one specimen of *Proptera laevissimia*, Pink Papershell, and two of Ebony Shell, *Fusconaia ebena*. The record of *P. laevissimia* is entirely credible, especially because the Academy found this species common in UMR Pool 3 below confluence with the St. Croix (Exhibit 111). Water quality in upper Pool 3 is inferior to that in the lower St. Croix, so there seems to be no reason why this Papershell should not occur at Hudson. The record of *F. ebena*, on the other hand, is almost incredible. The Ebony Shell is almost extirpated in the UMR drainage, not necessarily because of water quality, but certainly because of a dearth of the preferred larval host (Fuller, 1978b). That *F. ebena* persisted in the St. Croix River is almost unthinkable in spite of that river's good water quality. The Principal Investigator suspects that Williams' record may be a misidentification of *Pleurobema rubrum*, the Pink Pigtoe, which is similar to the Ebony Shell and was recently recorded alive from the Hudson site by the Academy (Exhibit 94). This supposition is strengthened by Williams' employing a somewhat out-of-date naiad taxonomy and giving no source for his mussel identifications.

6. Catfish Bar (Exhibits 5, 95, 199, 210)

Dredging at this Site has been confined to small quantities of material removed in 1937 and 1968 (USACE, 1974b), despite the fact that the area features many sandbars. Presumably, local currents are such that the bars do not often shift into positions that interfere with navigation. On the other hand, there can be little doubt that bedload is mobile at this Site, because so few living mussels were found, as is characteristic of unstable substrates.

7. Kinnickinnic (Exhibits 6, 96, 199, 211)

This is among the more frequently dredged Sites in the St. Paul District. Removal of streambed material rarely has occurred on a large scale, but took place during 15 of the 39 years in the period 1934 through 1972 (USACE, 1974b). The most recent dredging occurred in 1974, when a small quantity of material was removed. The Kinnickinnic River delta at its confluence with the St Croix forms most of this Site, which, because of the resulting unstable sands, probably has never been hospitable to mussels. Recurrent dredging doubtless has contributed additionally to the poor fauna indicated by the Academy's samples.

Black River (Exhibits 97, 203, 204)

Corps dredging in the Black River has been infrequent and small-scale in comparison to channel maintenance dredging in other rivers within the 9-Foot Navigation Channel Project. The impact of this work upon mussels cannot be ascertained because no pre-Project mussel data exist for the Black River. The only recorded information is a result of recent surveys by Havlik (1978a) and by the WDNR, which realized 17 species-group mussel taxa. This is a good, but hardly excellent total for a UMR tributary. It is highly probable that factors (e.g., declining water quality) other than Corps activities are at fault.

Upper Mississippi River (Exhibits 98, 195)

Within the confines of the 9-Foot Navigation Channel Project, the Upper Mississippi River drainage areas considered in the present study consisted of four reaches: the UMR itself and the lowermost (Corps-maintained) Minnesota, St. Croix, and Black Rivers. The latter three components of the study area already have been discussed, although the confluence of each with the Mississippi lies below the northern limit of the area (i.e., Head of Navigation above the Twin Cities). This organization permits discussion of the UMR study sites in unbroken sequence. The order of Exhibits in Appendices B and C reflects this arrangement of Site discussions.

In the definitive fashion stipulated by the 1977 and 1978 Scopes of Work for this project, the Academy studied 93 Sites in the Upper Mississippi River. The total mussel surveillance given this part of the study area was somewhat more extensive, however, since numerous other sites received cursory treatment during the study period. Many are considered in the relevant pool-specific discussion among those that follow.

In 1977 the Academy studied sites in both the Rock Island and St. Paul Districts (Fuller, 1978b), but the 1978 and 1979 study area involved the latter only. Accordingly, in order to provide a more clear and accurate picture of conditions in the St. Paul District, Exhibits 90 and 98 include data from that District alone whereas their counterparts in the Academy's report of its 1977 field work (Fuller, 1978b: Exhibits 49 and 53) represent results of two-District surveillance.

Above Upper St. Anthony Falls (USAF) Pool

The Upper and Lower St. Anthony Falls Locks and Dams were constructed during 1950's-1960's. Until about 25 years ago, the St. Anthony Falls (at the Twin Cities, Minnesota) formed a

natural barrier to the movements of UMR fishes and to the vagility of mussels whose glochidia are parasitic upon these fishes. Locks at the St. Anthony Falls probably now permit fishes of the lower UMR to pass into the Mississippi River above the Falls. However, there are no mussel records that would substantiate this claim, perhaps because there has been no comprehensive mussel surveillance of the uppermost Mississippi River drainage since the work of Wilson and Danglade (1914) in 1912, although Dawley (1947) did add a few records.

These points do not alter the fact that the historical naiad fauna in the UMR drainage above the St. Anthony Falls consisted of only nine species-group taxa (or only about one sixth of the recorded UMR mussel fauna). The reason usually given for the poor representation of the UMR mussel fauna above the Falls is that they formed an effective impediment to fish migration and thus to mussel vagility. It is, of course, possible that glochidially infested fishes selectively reached the uppermost UMR during graduations in the development of the St. Anthony Falls. However, were that the case, most vector fishes (and their parasites) should have gained the UMR reach above the Falls during the probably centuries-old maturation process of the Falls. This obviously has not occurred. The role of the Falls in the development of the upstream mussel fauna may have been at least as important as has been supposed.

Recent naiad migration northward probably began during the early pluvial period following the Wisconsonian glaciation. Modern mussels of the uppermost Mississippi River drainage probably followed glacial meltwater as parasites on fishes. These mussels probably used a variety of hosts; both parasite and host doubtless were somewhat insensitive thermally. Clarke's (1973) monograph of Canadian mollusks includes a number of freshwater mussels, most of which also occur in the UMR. Range extension of many of these animals, probably as parasites on host fishes, probably was facilitated by meltwater. When meltwater subsided after hundreds (and perhaps thousands) of years, the modern Mississippi River began to form, and persistent bedrock across its course gradually created falls, which impeded upstream movement of fluviatile organisms. The St. Anthony Falls, which fell most of 100 feet during recorded time, probably became an impenetrable barrier to the vagility of mussels in the form of larvae on host fishes. At that point in time recruitment to the naiad fauna above the Twin Cities probably came largely to a halt. The naiad fauna in the upper-

most UMR that was recorded by Dawley (1947) probably has changed little during the meantime. That Dawley's (1947) records of mussels in the Mississippi above the St. Anthony Falls differ from Clarke's (1973) fauna in central Canada suggests that elsewhere the recession of glacial meltwater may have created corridors of mussel colonization that were different from (and perhaps superior to) those that were available in the post-glacial UMR basin.

This line of thought has suggested at least one reason for the impoverished UMR naiad fauna that exists (or once existed) above the St. Anthony Falls. Analysis of the species in the modern mussel fauna of that reach offers a little insight into that fauna.

The mussel fauna in the UMR drainage above the Falls consisted (and perhaps still consists) of Mucket (*Actinonaias carinata*), Black Sandshell (*Ligumia recta*), Fat Mucket (*Lampsilis radiata siliquoidea*), Pocketbook (*L. ovata ventricosa*), Creek Heelsplitter (*Lasmigona compressa*), Cylinder (*Anodontoides ferussacianus*), Giant Floater (*Anodonta grandis*), and Strange Floater (*Strophitus undulatus*) (Wilson and Danglade, 1914). Dawley (1947) added Paper Floater (*A. imbecillis*), bringing the list to nine, but inexplicably omitted *S. undulatus*, although Wilson and Danglade (1914) appears in her bibliography.

These nine are, in part, a study in contrasts, and the reasons for the heterogeneous composition of this fauna are largely a mystery.

Three of the nine have unusually large numbers of recorded host fishes: Mucket (12 hosts), Fat Mucket (13), and Giant Floater (22) (Fuller, 1974, 1978b). Some of their hosts could have penetrated above the Falls by following glacial meltwater and/or by crossing the fall line early in the Falls' development. As noted earlier, mussels with very large numbers of hosts probably have the greatest vagility.

The presence of these three above the Falls seems easily rationalized, but another species, Threeridge (*Amblema plicata*), has many hosts (15), but has not been found above the Falls. In fact, none of its relatives, the heavy-shelled, "primitive" species in the naiad groups Ambleminae: Amblemini and Elliptionini occurs here. This phenomenon seems more than coincidence, especially because fully 14 species (28% or almost one third of the UMR fauna) are included in these two groups. No explanation is available. It may be that some of these species did colonize the uppermost MR at one time, but did not survive. The mystery remains, however, because some of them fare well in smaller streams and because characteristically large-river mussels comprise most of the fauna above the Falls today.

The heaviness of shell that characterizes the tribes Amblemini and Elliptionini probably is not the reason, because other such species (Fat Mucket and Pocketbook, which can be very heavy) are (or were) well established above the Falls; conversely, their Endangered congener Higgins' Eye, *Lampsilis higginsi*, ordinarily has a very heavy shell, but has never been recorded there.

Other elements in this fauna are comparatively understandable. The Cylinder has nine known host fishes, all normally small-stream species, and the Creek Heelsplitter has none. However, the two are small-stream species that rarely have been recorded from the UMR below the Falls. The Strange and Paper Floaters are alike in having few recorded hosts and in being two of the three Nearctic mussels whose metamorphosis has been claimed to be facultative (the Threehorn, *Obliquaria reflexa*, also in the UMR, is the third). In addition, the early juvenile Paper Floater can be a plankter (L.S. Tilly, personal communication *in* Fuller, 1980a). Occasional independence from glochidial host(s) may be an important factor in these two Floaters' great geographic ranges, including much of the UMR and its drainage both above and below the St. Anthony Falls. Either or both could have reached the uppermost UMR and its drainage by moving over the Falls as a parasite on fishes or by following glacial meltwater. The latter approach seems the more likely in that a facultative parasite's young would be carried downstream at least some of the time.

In comparison to those just discussed, a ninth species, Black Sandshell, is an oddity in that it is obligately parasitic, on few recorded hosts, and is (or was) perhaps the most widely distributed and successful mussel above the Falls (see Dawley, 1947).

Much research in numerous disciplines must be accomplished before a thorough understanding of the headwater and immediately downstream UMR mussel fauna can be gained. In the meantime it is possible that alien bivalve species (unionids and *Corbicula fluminea*) may penetrate to this reach because of the locks in the Upper and Lower St. Anthony Falls Locks and Dam installations.

USAF Pool and Below

Unlike the UMR reach above the USAF Pool, the reach below is not a zoogeographic mystery in terms of naiad distribution. When Wisconsin glaciation ended some thousands of years ago, the modern UMR began. It was gradually recolonized by southern populations. Most of these animals are large-river species (some are more nearly eurytopic) that had dwelt in appropriate waterways during the glacial advance southward. The modern UMR mussel fauna consists chiefly of species that are typical

of larger, permanent waterways in the Mississippi River basin. In addition, some species that are typical of the Cumberlandian and perhaps the Ozarkian faunae entered the UMR. Finally, a number of characteristically small-stream elements marginally invaded the UMR naiad fauna. The latter two groups are essentially extralimital to the UMR and predictably are the part of the mussel fauna that has suffered most as a result of man's environmental disturbance of the UMR during the last century or so.

As is shown in the accounts that follow (and in Appendix C), the modern UMR mussel fauna has lost most of its original elements that might be termed extralimital (i.e., Cumberlandian and small-stream species). Most of the balance are species that tolerate both large rivers and environmental degradation.

In the UMR these animals are distributed in three contiguous, but quite distinct zones of naiad life: the Twin Cities, Chippewa, and Recovery Zones. These concepts are introduced as an aid in succinct characterization of this fauna. Although the Corps viewpoint is that the lowermost, navigable reaches of the Minnesota, St. Croix, and Black Rivers are parts of the pools to which they are tributary (Pools 2, 3, and 8, respectively), these three zones of naiad life apply only to the mainstem UMR. This should be so because the mainstem does not flow into the tributaries; it influences them only to the extent of increasing their depths for finite reaches upstream from confluence.

The Twin Cities Zone of mussel distribution begins with the Upper St. Anthony Falls Pool and extends downriver to the confluence of the Mississippi and Chippewa Rivers at the foot of Lake Pepin in lower Pool 4. Although UMR water quality is favorably influenced by the St. Croix River, as is demonstrated by the superiority of the Pool 3 naiad fauna in comparison to that of Pool 2, this improvement is slight and certainly does not result in a truly healthy mussel community. It is widely and confidently considered that Lake Pepin serves as the most important catch-basin for water-borne wastes from the Twin Cities and surrounding urban areas and that water quality therefore must sharply improve below this natural river-lake. Because this study concentrated on the main channel and its borders, not all available mussel habitats in lower Pool 4 (and elsewhere in the study area) could be investigated. The Academy's evidence of mussel distribution below Lake Pepin thus is limited, and it probably is not a fair reflection of water quality below the Lake. In any event, this issue is obscured by the large quantity of sand that enters the UMR from the Chippewa at that point.

This moving, sandy bedload is the principal characteristic of the Chippewa Zone. This zone includes Pool 4 below the

Chippewa-Mississippi confluence, plus Pools 5 and 5A. The enormity of this bedload in terms of its very apparent impact upon mussels is readily inferred from relevant Pool- and Site-specific discussions offered below (see, also, USACE, 1974b). Moving bedload originating in the Chippewa River probably is not the only negative influence on mussels in the Chippewa Zone. Others include bedload from other streams (e.g., the Zumbro River, which enters Pool 5A); pollutants from the Twin Cities Zone that perhaps persist into the Chippewa Zone, as intimated above; and non-point-source biocides that are carried into this zone as a result of poor land use (e.g., sheet erosion). Adverse impacts upon mussels of the Chippewa Zone perhaps are not limited to these three factors. In any event, the three appear to have abated sufficiently above Locks and Dam 5A to permit substantial recovery of health in the mussel fauna.

Primarily because of the sudden and unforeseen improvement in the UMR mussel fauna that was found in the nursery beds opposite Winona, Minnesota, the Recovery Zone is here construed as the rest of the St. Paul District UMR reach through Pool 10. It is probable that the Recovery Zone extends downstream into the Rock Island District and possibly as far as the mouth of the Des Moines River below Keokuk, Iowa. It certainly extends no farther; the excellent mussel fauna at Keokuk is almost eliminated by the confluence with the Des Moines, probably because of the poor quality of this tributary's waters. The Recovery Zone eventually may require redefinition in the light of further information about mussels lying between Locks and Dams 10 and 19.

Upper St. Anthony Falls (USAF) Pool (Exhibits 99, 196)

8. SOO Line Railroad Bridge (Exhibits 7, 100, 196, 212)

9. Broadway Avenue and Plymouth Avenue Bridges (Exhibits 8, 101, 196, 212)

As reported by Fuller (1978b):

> Surveillance of the first and third of these Sites included the second, also, and amounted to coverage of almost the entire Pool. Because of the environmental and informational homogeneity of this reach, the Pool and its Sites are discussed as a unit.
>
> Beginning in 1963, almost the entire length of the main channel in this Pool has been dredged at one time or another, but disposal of material occurred elsewhere (USACE, 1974b). Continued dredging and, at last, local disposal sites are contemplated. Such activities cannot have done, or be expected

imminently to do, any damage to the Upper St. Anthony Falls Pool mussel fauna, simply because there evidently is none.

St. Anthony Falls formed a natural barrier to upstream penetration by mussels. Only a small fraction of the fauna of the lower reaches surmounted the Falls and gained the Mississippi headwaters (Dawley, 1947): *Actinonaias carinata*, *Ligumia recta*, *Lampsilis radiata siliquoidea*, *L. ovata ventricosa*, *Lasmigona compressa*, *Anodontoides ferussacianus*, *Anodonta imbecillis*, and *A. grandis*. Most of these have large numbers of glochidial hosts and thus doubtless have had plentiful opportunity for introduction above the Falls during their larval phase. Apparently the availability of glochidial hosts is not the only requirement for some species to extend their ranges into the area above the Falls. For example, *Amblema plicata*, which has many hosts and is environmentally very adaptable, has never been discovered there.

Lasmigona compressa and *Anodontoides ferussacianus* are characteristically small-stream species and are not likely ever to have inhabited the St. Anthony Falls Pools. A balance of only six mussel species, then, forms the core of the fauna that might be expected immediately above the Falls.

It is thus hardly surprising that so few dead shells were found in the Upper St. Anthony Falls Pool. What *is* surprising is that almost *no* mussel material could be found. Evidently, all naiades here were destroyed long ago. It is equally clear that recolonization in the foreseeable future will not occur. Water quality in this urbanized reach is doubtless prohibitive, and Ponar dredging revealed that much formerly suitable riverbed is now overlain by muck. It is a curious footnote to these remarks that the Academy has been unable to discover any historical mussel records that are definitely referable to this Pool. It may never have provided optimal naiad habitat, at least since thick settlement by European man began about a century ago, but a more probable explanation is that early local naturalists happened not to record mussel data appropriate to this report.

Information about Corps dredging in the USAF Pool has been updated since the previous report (Fuller, 1978b) of the 1977 study. The SOO Line Railroad Bridge Site was dredged in 1976, 1978, and 1979. A large total quantity of riverbed material was removed. The Broadway and Plymouth Avenues Bridges Site was perennially and heavily dredged during the period 1973 through 1979. This pattern of heavy, more or less continuous dredging shows no sign of abatement. The moving bedload that necessitates the dredging and the dredging itself will probably continue to militate against mussels' recolonizing this Pool.

Lower St. Anthony Falls (LSAF) Pool (Exhibits 102, 196)

In regard to the 1977 study, Fuller (1978b) reported:

> The Corps has done minimal dredging in the Lower St. Anthony Falls Pool (USACE, 1974b). The Academy did not sample in this Pool and has been unable to locate relevant mussel records of any kind. It is highly probable that adverse conditions, past and present, noted in the Upper St. Anthony Falls Pool (just above) exist here, as well. Therefore, Corps dredging could hardly have done mussels any damage.

The Academy did not study the LSAF Pool in either 1978 or 1979. The Principal Investigator is unaware of dredging in the Pool since 1972, the last dredging season recorded in the St. Paul District EIS (i.e., USACE, 1974b).

Pool 1 (Exhibits 103, 196)

10. Lake Street Bridge (Exhibits 9, 104, 196, 213)

11. St. Paul Daymark 849.1 (Exhibits 9, 104, 196, 213)

12. Locks and Dam 1 Upper Approach Construction (in part) (see Pool 2, below) (Exhibits 11, 106, 196, 198, 213)

As previously reported (Fuller, 1978b):

> Again because of their environmental and informational homogeneity, the Pool and its Sites are discussed as a unit.
>
> Mussel records available to the Academy that are definitely identified with this Pool are limited to the species whose bones were discovered at the St. Paul Daymark Site. However, there can be no doubt that Pool 1 once shared the rich naiad fauna of the Upper Mississippi River below St. Anthony Falls. The quantity and the specific identities of current bones are sufficient proof.
>
> As above the Falls, the fauna here has been devastated, though it is probable that the destruction concluded in Pool 1 at a later date than in the St. Anthony Pools. Some bones from this Pool are fresher than those from the latter, though all are of great age.
>
> With increasing extent and frequency, the Corps has dredged in Pool 1 since before the Second World War. Now much of this reach is dredged during most years (USACE, 1974b). This is very intensive maintenance, but it has probably never done much if any damage to mussels, because apparently the fauna was essentially destroyed decades ago. Dredge sampling by

the Academy revealed only sand and muck; these inhospitable substrates, plus other sources of ecological adversity (e.g., low dissolved oxygen, heavy metals, etc.), probably have been the norm for many years. Thus it appears that chances for foreseeable recolonization by mussels are remote.

Information about Corps dredging in Pool 1 has been updated since the Academy's report (Fuller, 1978b) on its 1977 study of the Pool. The Lake Street Bridge Site was dredged almost perennially during the period 1973 through 1979; a very large total amount of riverbed material was removed. The St. Paul Daymark 849.1 Site was dredged somewhat less frequently during the same period; a somewhat lesser total quantity of material was removed. Also during the same period, the upper approach to Locks and Dam 1 was moderately dredged several times. These high levels of dredging and the moving bedload that requires them combine to create an environment that essentially is hazardous to mussels. There seems to be no reason to suppose that this pattern of almost uniformly heavy bedload and dredging will soon cease.

Pool 2 (Exhibits 57, 107, 198)

As Fuller (1978b) reported:

> In terms of its naiad fauna this reach has been and is superior to those above. There are some historical records, a few current ones, and even one Site where living mussels were found during this project. (At the other Sites, however, there was only the devastation observed in the upper Pools.) Muck was the prevalent streambed in most areas. There were no submerged vascular vegetation and few bones, all very old. Probably the Twin Cities and the Minnesota River both negatively influence Pool 2.
>
> The Corps' dredging this Pool began in 1937, but has been more sporadic in space and time than is the case upstream (USACE, 1974b). The finding of an extant mussel community suggests the possibility that the Corps may have disturbed freshwater mussels slightly -- but only *very* slightly -- more in Pool 2 than in those above.

Information about Corps dredging in Pool 2 has been updated since the Academy's report (Fuller, 1978b) on its 1977 study of this Pool. A moderate total quantity of material was removed from the Smith Avenue Bridge Site by dredging conducted most years during the period 1973 through 1979. The Robinsons Rocks Site experienced light dredging in 1977. Very large amounts of riverbed material were taken from the vicinity of the Boulanger Bend Site in 1974; the Site itself had been lightly dredged in 1973. The correlated phenomena,

heavy bedload and heavy dredging, are disadvantageous to mussels, and dredging occurred at Smith Avenue Bridge as recently as last year. In addition to such adversities as poor water quality, which has been a problem in this UMR reach for three-score years (Grier, 1922, 1926a; Ellis, 1931a, 1931b), continued bedload and dredging indicate inferior conditions for mussel colonization in the years to come. This indication is common to the UMR above Pool 2, as well, but is ironic in this Pool because mussels persist in at least one reach, the lower approach to Locks and Dam 1. Following Corps directions pursuant to the Scope of Work, the Academy did not conduct mussel surveillance throughout Pool 2, and not all available habitats were sampled. It is possible that some mussels remain in this Pool. Nevertheless, prospects for a foreseeable mussel renaissance are negligible at this time.

12. <u>Lock and Dam 1 Upper Approach Construction (in part) (see Pool 1, above) (Exhibits 11, 106, 196, 198, 213)</u>

In reporting on the 1977 field work, Fuller (1978b) observed:

> There are several noteworthy points. First, this is a construction Site. Some dredging is doubtless involved, but it is not for channel maintenance.
>
> Second, the construction is undertaken above the Locks and Dam, in Pool 1 (which see, above), but most of the investigative area lies below. For this reason and especially because living mussels were found there, this Site is discussed as though its entirety lay in Pool 2.
>
> Third, mussels began in the dam tailrace and continued the length of the Site; none was found immediately below the Locks, where the Corps has dredged in the past (USACE, 1974b). Whether there is a casual [*sic*: causal] relationship between these two points is unknown and probably unknowable.
>
> Fourth and unfortunately, this population shows poor condition. It is very sparse and sporadic, even though it extends (discontiguously and primarily along the left bank) for almost a mile. There was no evidence of recent recruitment, although fertilization is possible at this Site (*Strophitus undulatus* was gravid). On the other hand, that the gravel riverbed appeared clean of silt and that the water obviously was adequately oxygenated are encouraging.
>
> Finally, one must wonder whether there are not other refugial populations thus far overlooked in the stricken uppermost Pools. If so, mussels could more rapidly reinvade those reaches if favorable water quality were restored to the Twin Cities vicinity.

13. Smith Avenue ("High") Bridge (Exhibits 12, 108, 198, 214)

Fuller (1978b) reported that:

> This is the only Site in Pool 2 where bones were found. All were very old, and many were spoiled by exposure, so identification is dubious in some cases. These dead shells cannot necessarily be interpreted as indigenous to this Site (see Hudson RR Bridge, above). They are thus admitted only to the list for Pool 2 (Exhibit 107).

14. Robinsons Rocks (Exhibits 13, 109, 198, 215)

As reported by Fuller (1978b):

> No living or dead mussels were found at this Site, and apparently there are no previous records.

Boulanger Bend (cursory)

This site was cursorily surveyed 21 July 1977 by the Principal Investigator with the aid of a St. Paul District launch and crew. No mussels, living or dead, were found, and apparently there are no previous records relevant to this site.

15. Nininger (Exhibits 14, 110, 198, 216)

As reported by Fuller (1978b):

> No trace of mussels was found at this Site. Dawley (1947) provided some historical records (Exhibit 107).

Pool 3 (Exhibits 111 and 199)

The Academy did not study this Pool in 1977. A few short reaches in the upper Pool were cursorily surveyed in 1978 with the help of the WDNR mussel survey crew (Fuller, 1978a). Later in that season the Academy's crew resurveyed those areas in the definitive fashion stipulated in the Scope of Work; the results are reported below. In 1979 the vicinity of the upper and lower approaches to Locks and Dam 3 was surveyed as part of Corps preparations for a program of dredging and construction (Fuller, 1979c).

Remarkably, as previously pointed out (Fuller, 1978b), there appear to be no published site-specific mussel records for Pool 3, even though the major museum collections probably include specimens from this Pool. Regardless of the available records, it seems reasonable to assume that *some* mussels must have occupied this reach in the past. The Principal

Investigator's initial interpretation of this Pool's naiad fauna was very negative (Fuller, 1978b). However, the Academy's 1978 opportunity to examine the Pool revealed a limited, but apparently viable fauna of hardy species. In this respect it contrasts sharply with the St. Anthony Falls Pools and Pools 1 and 2 (see Fuller, 1978b), which are nearly devoid of naiades. This new interpretation of Pool 3 mussel populations is one of the bases for the previously described recognition of discrete zones within the UMR defined by the characters of their naiad faunae.

The channel-maintenance history of Pool 3 is greatly detailed (USACE, 1974b). Dredging began in 1934 (prior to the 9-Foot Navigation Channel Project) and continued, somewhat irregularly, throughout the Pool at least until 1972, the most recent year of public record. The only channel-maintenance dredging since that time involved removal of a moderate amount of riverbed material at the Coulters Island Site. Because of this homogeneous record, the Site-specific remarks offered below omit dredging history and concentrate upon the mussel fauna. Even so, the remarks are brief because the very impoverished naiad fauna offers little opportunity for Site-specific commentary and because so many of the Sites are contiguous.

This contiguity has the added disadvantage of making it nearly or entirely impossible to report separately upon the mussel faunae of certain Sites. For example, the Coulters Island and Morgan Coulee Sites occur within the same river mileage. Consequently, brailing of this reach was conducted without any attempt to distinguish between the two nominal Sites, and their results are reported together.

16,17. Vermillion River and Hastings Small Boat Harbor (Exhibits 15, 16, 112, 113, 199, 216)

No living mussels were found in either the Vermillion River or the Harbor Site.

18,19. Prescott and Pine Coulee (Exhibits 17, 18, 114, 115, 199, 217)

These two, largely contiguous (and, in terms of river mileage, indistinguishable) Sites exhibit a largely undistinguished mussel fauna. However, some Spike, *Elliptio dilatata*, and the Strange Floater, *Strophitus undulatus*, were taken. That these rarities were found at all is a favorable commentary upon water quality in Pool 3, especially because, as a small-stream element, *S. undulatus* is not necessarily to be anticipated in any UMR Pool.

20, 21. Truedale Slough and Four Mile Island (Exhibits 19, 20, 116, 117, 199, 217)

Only 40 living mussels were taken at these Sites. The most common species was *Fusconaia flava*, as was true of the St. Croix River fauna. This suggests that the naiad fauna of Pool 3 is favorably influenced below confluence of the UMR with the St. Croix.

22. Big River (Exhibits 21, 118, 199, 218)

This Site's mussel fauna resembles the St. Croix River naiad community (e.g., it exhibits dominance by *Fusconaia flava*). A lone specimen of Spike, *Elliptio dilatata*, was taken here, and a single living Paper Floater, *Anodonta imbecillis*, was found at this Site. These captures are further evidence of not only the favorable impact of St. Croix River water upon the UMR, but also the remarkable environmental tolerance of this Floater.

23, 24. Morgan Coulee and Coulters Island (Exhibits 22, 119, 199, 219)

At Sites farther upstream in Pool 3, domination of the naiad fauna was by *Fusconaia flava*. However, at the present Sites the dominant mussel species was *Amblema plicata*, the Threeridge, as is typical of UMR pools. The success of the Threeridge is discussed below. The Threehorn, *Obliquaria reflexa*, was a co-dominant at this Site.

25. Diamond Bluff (Exhibits 23, 120, 199, 219)

Domination of the fauna remains with *Fusconaia flava* at this Site, but, in classic UMR pattern, this dominion is shared with the more tolerant species, such as Threeridge and Pimpleback (*Quadrula pustulosa*). The favorable influence of St. Croix River water quality apparently wanes in lower Pool 3.

Pool 4 (Exhibits 121, 200, 201)

This is the longest UMR Pool in the St. Paul District. It is divided into three unequal parts by Lake Pepin, a natural river-lake (as opposed to the Pools, the artificial river-lakes, that were created by the 9-Foot Navigation Channel Project). The reach above Pepin includes eight sites surveyed by the Academy in 1978, including several areas in the vicinity of the Trenton Site that had been cursorily investigated earlier in the year (Fuller, 1978a). One Site in Lake Pepin was examined in 1977 and 1978. Six more in the reach below Pepin were surveyed in 1977 or 1978. In addition, the Academy sur-

veyed a reach both above and below Locks and Dam 3 in anticipation of reconstruction of a portion of that installation. The surveillance indicated that the project would not be hindered by the presence of mussels, Endangered or not. Details may be found in Fuller (1978b):

> Almost the entire Upper Mississippi River mussel fauna, including the Endangered *Proptera capax* and *Lampsilis higginsi*, is known historically in Pool 4. However, only 19 species have been encountered recently, and only 12 were found alive in 1977. This remarkable decline is either real or an appearance caused by insufficient investigation.
>
> A marginal commercial mussel fishery still exists in Lake Pepin, and some small beds have persisted (Jim S. Engel, personal communication, St. Paul District, Corps of Engineers). Nevertheless, great abatement of clams and clamming has occurred since the heyday of the Lake Pepin Mucket, perhaps the greatest button shell of them all (see Coker, 1919). The phenomena behind Pepin's notoriety as a kind of catch basin for Twin Cities wastes surely are largely to blame. It is probable that faunistic decline is more real than apparent in this river-lake.
>
> As a catch basin, however, Lake Pepin reduces adverse impact from the upper reaches upon the more riverine, lower portion of Pool 4 below the Chippewa River, just as the St. Croix River, entering this Pool at its head, has a diluting and thus favorable influence upon the adverse impact caused by Pool 3. One might, then, expect the modern mussel fauna to improve below Lake Pepin, although the negative influence of the Chippewa on Mississippi naiades in this area must be considered.
>
> That Chippewa alluvium helped create Lake Pepin and influenced the Mississippi below is an established feature of the regional geologic record. At one time, this influence alone could not severely have limited mussel populations, because the Ellis survey records show that lower Pool 4 (Zone II of the van der Schalies, 1950) supported at least 29 species as late as 1930 and 1931. If the poor records of recent years are to be credited, in full or only in part, an additional adverse impact must have intervened at some point after Ellis' work. Could increased land use in the Chippewa watershed by an expanding human population have increased its alluvial contribution to the Mississippi? Is it only coincidence that extensive, increasing, and now almost perennial dredging by the Corps below Lake Pepin began in the mid-Thirties (USACE,1974b)?
>
> On the other hand, maintenance dredging and associated activities are confined chiefly to the main channel. This truism revives an earlier question, now expressed in a different way: are there extant mussel species in non-channel habitats of Pool 4 that were not investigated during the Academy project? Another type of investi-

gation might demonstrate that the Pool 4 mussel fauna is, in fact, superior to what present evidence suggests.

In any case, the Upper Mississippi main channel in lower Pool 4 carries a substantial bedload, which is commonly attributed to the Chippewa. Dredging there is necessary for precisely the same reason that mussels cannot succeed, namely, heavy deposits of shifting sand. There can be no reasonable doubt that Corps maintenance in lower Pool 4 has killed many mussels, mainly juveniles, probably including some Endangered ones, but these individuals, isolated and for the most part doomed by the shifting sand, could not have contributed to the populations of their respective species (see discussion of *Truncilla donaciformis*, below).

Bedload from the Chippewa River is principally responsible for the concept of the Chippewa Zone in modern naiad distribution in the UMR. The Chippewa is not the only contributing factor, however; 60 years ago Grier (1922) recognized the Cannon and Zumbro rivers as significant sources of bedload in the UMR reach that is now Pool 4 (the two rivers enter this Pool near Red Wing and Wabasha, Minnesota, respectively).

The combined sand and mud from these tributaries nevertheless apparently had never been a serious deterrent to mussels. In addition to the then famous "Trenton bed" (near the Trenton Site) and "good clamming" locally in Lake Pepin, other important mussel communities were remarked by Grier (1922, 1926a) at Wabasha; Teepeeota Point (at or near the Corps dredging Site of the same name); and Alma, Wisconsin.

On the other hand, Grier (1922, 1926a) noted that in 1920 these great beds were no longer of their previous quality and extent and had conspicuously worsened by 1925, only five years later! Grier considered wing dams the primary factor in this rapid degradation and emphasized the tendency of these structures to divert sand from the navigation channel into the channel borders. On the strength of numerous, in some cases repeated observations, he concluded that channel-border sand had smothered many mussel beds. Also, he cited reoriented, unusually swift currents, influenced by wing dams, as the cause of mussels' (especially juveniles') being swept away from substrates that formerly had been relatively undisturbed.

In addition to the role of wing dams in the deterioration of mussel beds, Grier (1922) indicted over-harvest, unnecessarily destructive methods of harvest, pollution emanating principally from the Twin Cities, and local municipal "rubbish". Most of Grier's observations are familiar to students of UMR naiades, partly because his points remain valid today.

Three of Grier's ideas were more or less pioneering and are even now inadequately appreciated. First, he realized that the Twin Cities are by no means the sole source of environmental degradation in the Twin Cities Zone of modern mussel distribution -- and beyond. Second, Grier recognized that man-made trash could have an adverse impact upon the behaviour of glochidial hosts, and he made this point with special respect to small towns. Third, he (with perhaps a few others) was well ahead of his time by paying attention to the presence/absence of juveniles in a mussel community; Grier interpreted lack (or even reduction) of juveniles as a clear negative reflection of the health of a community. Perhaps only the present study and the WDNR mussel survey have adequately followed Grier's lead in this respect.

This discussion of Grier's (1922, 1926a) work and findings is included at this point in this report because most of his published study of UMR mussels was devoted to what eventually became Pool 4. This devotion probably was caused by the fact that in the early Twenties an area such as Pool 4 -- beyond the range of severe pollution from upstream and near the northern terminus of mussel harvest, which had begun far downstream in Iowa 40 years previously -- was the best suited to studies of the potential commercial mussel fishery for the then Bureau of Fisheries. Such a focus of early mussel investigation is unique among UMR reaches, except perhaps for the vicinity of Fairport, Iowa (now in Pool 16), where the staff of the Bureau's mussel propagation laboratory did much of their work (Coker, 1916, 1919, 1921; Coker et al., 1921). Pool 4 seems unique in another respect: it is perhaps the only Pool to which an entire modern mussel study (Morrison, 1959) has been devoted.

Morrison (1959) compared his own collections at several Lake Pepin Sites to the results of the Ellis (1931a, 1931b) survey (synopsized by van der Schalie and van der Schalie, 1950) at almost the same localities 30 years earlier. Although Morrison found about 20 mussel species-group taxa alive, a distinct decline in number and variety of these taxa was apparent.

This result exemplifies the degradation of the mussel fauna in Pool 4 that has taken place during the last half-century. This phenomenon apparently is shared among all UMR Pools. It is emphasized here because knowledge of Pool 4 happens to include an unusually graphic record.

26. Above Trenton (Exhibits 24, 122, 200, 220)

Dredging was frequent here at one time, and some large quantities of material have been removed (USACE, 1974b). However, there was none after 1975, when a moderate amount of river-

bed was removed. Had suitable habitat been available, the intervening period should have been long enough to permit development of a fauna superior to the one in evidence in 1978. Very few specimens were found at this Site, but these included some juveniles (of various species) and an adult *Anodonta imbecillis*, uncommon in the UMR.

27. Trenton (Exhibits 25, 123, 200, 220)

The Trenton Site has experienced almost forty years of dredging (usually moderate), continuing at least until 1971 (USACE, 1974b). Nevertheless, the 12 species of living mussels encountered here are a substantial improvement upon the poor fauna at the Above Trenton Site (above). The samples are remarkable for a thriving population of large, healthy Pink Papershell, *Proptera laevissima*, and for a single living Fat Mucket, *Lampsilis radiata siliquoidea*, which is near extinction in the UMR. The "Trenton bed" described by Grier (1922) was probably located near this Site.

28. Cannon River (Exhibits 26, 124, 200, 220)

A very poor mussel community was observed at the Cannon River Site. Dredging at this Site has a lengthy history (1935 through at least 1972; USACE, 1974b), though it was rarely heavy. On the other hand, a large amount of material was dredged in 1973. A more likely cause of the poor mussel fauna is moving bedload from the Cannon River, which creates the need to dredge. More than half a century ago Grier (1922) noted the quantity of bedload from the Cannon River discharged to the UMR reach that is now Pool 4 and the possible, natural adverse effects that this discharge may have had upon nearby mussels.

29. Red Wing Commercial and Small Boat Harbors (Exhibits 27, 125, 200, 220)

Only two living mussel specimens were found at this collective Site. Light dredging was conducted at the Commercial Harbor as recently as 1978; it could have done no serious damage to mussels.

30. Red Wing Highway Bridge (Exhibits 28, 126, 200, 221)

This Site's mussel community was poor in 1978, though noteworthy because two juvenile *Anodonta imbecillis* were taken. Dredging, usually light to moderate, occurred here from 1935 through 1972 (USACE, 1974b). An unspecified quantity of material was removed in 1974.

Also unspecified is a place "above Red Wing" (but perhaps as close to this Site as to any in the vicinity) where

Grier (1922) found a diversified mussel community, including the Endangered *Lampsilis higginsi*, Higgins' Eye. Grier emphasized finding the conchologically similar Hickorynut, *Obovaria olivaria*, in this area. Even then this comparatively common species was dwindling in the upper reaches of the UMR. On the other hand, Grier's record was equalled in upper Pool 4 by the WDNR mussel survey (P. Thiel, personal communication, WDNR, La Crosse). If formerly common species that have become noteworthy rarities are recorded 60 years apart in essentially the same study area, the implication is that mussel degradation was about equal at both times. It is encouraging to suppose that, at least in general, the Pool 4 mussel fauna is little or no worse than it was even well before impoundment by the 9-Foot Channel. This inference, however, is specious to the extent that this fauna is clearly much less species-rich than it was 50 years ago. A comparison of Morrison's work to the van der Schalies' (1950) report on Ellis survey results will make the point (see Pool 4, above).

Grier (1922) noted an unusual abundance of juvenile mussels (byssally attached to dredge and weed beds) "below Red Wing". This result contrasts sharply with the Academy observations in 1978.

31. <u>Bay City Small Boat Harbor</u> (Exhibits 29, 127, 200, 222)

No trace of mussels was found at this Site.

32. <u>Bay City Commercial and Recreational Sites</u> (Exhibits 30, 128, 200, 222)

The mussel samples were limited to three living *Proptera laevissima*. That these animals could tolerate the very adverse conditions in an area of intense human activity is further proof of the Pink Papershell's hardiness.

There seems to be no record of Corps dredging at Site 31 or 32. Their mussel faunae nevertheless are very poor. One form or another of human intervention doubtless is at fault. These faunae contrast sharply with Grier's (1922) observation of a very good mussel community in the Bay City vicinity in 1920.

33. <u>Wacouta Point</u> (Exhibits 31, 129, 200, 222)

This Site has an unusual dredging history. First in 1938 and as recently as 1969, enormous amounts of material have been removed, but on only a few occasions (USACE, 1974b). Moreover, the dredge cuts here ordinarily have been very long, the longest (again in 1969) extending over two miles.

One might think that these factors would have devastated the mussel fauna. Certainly this must have been true in the main channel during extensive dredging, but there has been some recovery. Although hardly plentiful at this Site, mussels are *not* devastated: the Academy found some alive in even the main channel. One also can infer, then, that the quality of water feeding from the polluted Twin Cities Zone has improved substantially by the time it reaches upper Pool 4. Some of the observations (above) on other Pool 4 Sites bear this out.

The samples from this Site include no unusual records except for an adult *Anodonta imbecillis*. This version of the Wacouta Point fauna differs sharply from Grier's (1922) remarking a comparatively diversified mussel community there in 1920.

34. Lake City Small Boat Harbor (Exhibits 32, 130, 200, 223)

As reported by Fuller (1978b):

> Surveillance of a very limited area, about the harbor mouth, was required. In that respect this Site was unlike all others in this project. The Lake Pepin floor here was of the sand and muck commonly associated with marinas. It was very unproductive of mussels and harbored no legally protected species. Dredging here can hardly damage the naiad fauna. Note, finally, that this is not a channel maintenance Site.
>
> Dawley (1947) gave "Lake City" mussel records (included in Exhibit 61 for the sake of historical perspective on the general area), but they cannot necessarily be referred to the Site. The Ellis survey worked just above Lake City, but the van der Schalies (1950) did not specify the findings; these records definitely should not be ascribed to the Site.

This excerpt concerns results of the Academy's 1977 field surveillance. This Site was additionally surveyed in 1978, when much more extensive brailing was conducted well downstream of the Harbor's mouth. The 1978 study reach was heavily shoaled; only six living mussels were found. Modifying the Lake City Harbor facilities can be undertaken with little risk of damaging mussels. The possibility of an Endangered Species' being encountered at this Site is remote.

These remarks are sharply at variance with results of other studies in the Lake City area. Grier (1922) found a degraded fauna, but it was much more varied and plentiful than the Academy discovered. Grier found unusually large numbers of juvenile mussels; the Academy survey revealed only one. Morrison (1959) found an additionally degraded mussel fauna, but his records, also, are far more numerous than the Academy's.

35. Reads Landing (Exhibits 33, 131, 201, 224)

As previously reported by Fuller (1978b):

> Commencing in 1934, the Corps dredged rather extensively at this Site during about one half of the years through 1972 (USACE, 1974b).
>
> Represented by very few individuals each, only five living naiad species were found at this Site. This total probably is augmented by numerous others suspected of persisting at the Site and/or in the immediate vicinity on the basis of earlier records for this area (see Exhibit 62).
>
> The Ellis survey worked this area, but the van der Schalies (1950) did not identify which species had been found.

This excerpt from the Academy's previous report, on 1977 surveillance, can be updated in various respects. First, this Site was heavily dredged almost perennially during the period 1974 through 1979. Second, Grier (1922) found that in the Reads Landing vicinity (including lowermost Lake Pepin) the abundance of Pool 4 juvenile mussels was second only to their numbers at Lake City. Third, Grier emphasized finding Butterfly, *Ellipsaria lineolata*, at or near the Reads Landing Site, whereas the WDNR mussel survey recently found this species only as far upriver as Pool 5A.

These points suggest that the UMR naiad fauna at and/or near the Reads Landing Site has declined during the past half-century or so, perhaps somewhat in response to Corps dredging. Although prevailing environmental quality may be sufficient to support certain rare taxa, the Academy did not find the great abundance of juvenile mussels revealed during the Grier survey. There thus seems to be a sharply diminishing probability of recruitment to the extant mussel community; this does not bode well for the mussel fauna at this Site.

36. Wabasha Small Boat Harbor (Exhibits 34, 132, 201, 224)

This otherwise unproductive Site (where only 17 living mussels were taken) exhibited several interesting features in 1978.

The Harbor itself (i.e., Trollen's Marina) apparently is devoid of mussels, as is usually true of marinas, but, beginning just below its mouth and extending at least as far as the Wabasha Highway Bridge, there is a relic bed of very old mussels along the Minnesota shore. This probably is the "remnant bed" at Wabasha that was noted by Grier (1922).

Even in Grier's day, this bed was already badly damaged, perhaps as a result of wing dams and/or "rubbish" dumped in the river.

Several rare mussels recently have been recorded from this bed. The WDNR mussel survey took *Cyclonaias tuberculata*, Purple Pimpleback (P. Thiel, personal communication, WDNR, La Crosse). National Biocentric (1979e) found *Quadrula metanevra*, Monkeyface; *Elliptio dilatata*, Spike; *Plethobasus cyphyus*, Bullhead; *Pleurobema rubrum*, Pink Pigtoe; and *Actinonais carinata*, Mucket. These two surveys were conducted by brailing and SCUBA. The Academy field team had the capability of SCUBA and HOOKAH diving, as well as brailing, but used only brailing at the Wabasha Small Boat Harbor Site. Further 1978 study of the mussel bed beneath the Wabasha bridge did not seem warranted, because diving is very time-consuming and brailing had already revealed this bed's existence. In any event, the Academy confirmed the presence of *Q. metanevra* and *E. dilatata*.

These findings reflect the reason why the Wabasha bed is important. Although relic and perhaps failing (the only juvenile found at this Site was the widespread and hardy Fragile Papershell, *Leptodea fragilis*), this bed is a potential source of recruitment of rare animals to a part of the UMR from which they have been essentially eliminated. This source of recruitment would become especially important should water quality improve and the quantity of bed load decrease. Conservation of this bed could be a very significant step, but it is now threatened by the Minnesota Department of Transportation's proposed replacement of the Wabasha Bridge (B. McCarthy, MNDOT, St. Paul, Minnesota, personal communication). If this construction takes place, parapet placement and associated activities could badly damage (or even eliminate) portions of the Wabasha bed. This is a situation in which state government and the private sector must follow the lead of Federal agencies (e.g., COE, FWS) if fullest conservation of the mussel resource is to be realized.

37. Crats Island Bank Repair (Exhibits 35, 133, 201, 224)

The Academy studied the Crats Island area cursorily in 1977 (Fuller. 1977), but the Corps has never instituted a formal channel-maintenance site of this name. The area lies between the 1977 Reads Landing and Teepeeota Point Sites, both of which supported poor mussel communities (Fuller, 1978b). The present Crats Island Site lies in a UMR reach that experienced almost perennial dredging from 1938 through 1972 (USACE, 1974b). In addition, the Crats Island vicinity was heavily dredged almost perennially during the period

1973 through 1979. In view of these points, plus the fact that this is a site of erosion (hence the need to repair the bank), it is not surprising that the Academy found no trace of mussels here. This is an area that is physically inhospitable to mussels and that would be more suitable to them if steps were taken to promote stable streambed nearby by reducing erosion. Bank repair can proceed here without fear of damaging what is now a non-existent resource. A final point about this Site is that it is one of the few bank repair sites in the study area that is not part of a channel-maintenance site.

38. Teepeeota Point (Exhibits 36, 134, 201, 225)

As previously reported (Fuller, 1978b):

> At this Site in 1936 the Corps began extensive and almost perennial dredging, which persisted through 1971 (USACE, 1974b).
>
> This Site exhibited a mussel assemblage only slightly less poor than the one from Reads Landing (compare Exhibits 62 and 63). The Academy has no relevant recent or historical records. Previous work at Crats Island upstream from the Site had produced nothing not found later at Teepeeota Point (Fuller, 1977a). The Ellis survey worked both areas, but the van der Schalie (1950) did not indicate which species had been found at either.
>
> Most of the Academy's adult material appeared to be remnant individuals from old beds associated with wing dams. Essential destruction of former beds would be an example of damage done by moving bedload in Pool 4 below the Chippewa.

It is now possible to update the preceding account of the 1977 field work. This Site (and vicinity) experienced heavy Corps dredging almost perennially during the period 1973 through 1979. Grier (1922) described a formerly extensive mussel bed near Teepeeota Point that in 1920 already was nothing more than a "remnant bed". A small assemblage of very old mussels that the Academy detected along the upstream border of a wing dam at this Site may be all that is left of the great Teepeeota bed.

39. Grand Encampment (Exhibits 37, 135, 201, 225)

Fuller (1978b) reported that:

> In 1937 at this Site the Corps began dredging that recurred a bit more frequently than every other year through 1970 (USACE, 1974b).
>
> The 1977 mussel samples are very poor. Submerged vascular vegetation containing juvenile mussels was occasionally en-

countered. The Academy has found no additional relevant mussel records.

Corps dredging data for this Site have been updated since this excerpt was written. Heavy dredging in 1973 was followed by removal of a relatively small amount of riverbed material in 1977.

40. Beef Slough (Exhibits 38, 136, 201, 225)

Like most channel-maintenance sites in Pool 4, Beef Slough has an approximately four-decade recorded dredging history (1938 through 1971; USACE, 1974b). However, in this case, unlike those below Lake Pepin, this Site has been dredged only moderately, in terms of frequency and amount of bedload removed. The most recent instance was in 1974, when light dredging was conducted.

The mussel fauna at this Site was not well developed, only eighteen living mussels, representing six species, being taken. These results are consistent with those for nearby (just upriver) 1977 Sites (see Fuller, 1978b).

Pool 5 (Exhibits 137, 201)

As previously reported (Fuller, 1978b):

> Pool 5 appears to have a richer mussel community, and to have experienced less dredging, than Pool 4. The inference is that moving bedload has here been the lesser problem to mussels *and* to the Corps....
>
> Evidence of a dredging program in Pool 5 that is comparatively favorable to mussels is that, although dredging persisted almost perennially after 1933 through 1971 and 1972 at West Newton and Weaver Bottom Complex, respectively, the amount of dredging per year was less than at Pool 4 Sites.
>
> Dennis Cin (personal communication, St. Paul District, Corps of Engineers) has pointed out that, at times of very high water, Pool 4 is permitted to drain, more or less unimpeded by Lock and Dam 4, into Pool 5. Bedload originating in the Chippewa River thus penetrates at least to the second Pool downstream from the Chippewa-Mississippi confluence. Mr. Cin added that the Zumbro River is believed *directly* to impact Pool 5 with migrating material. It seems that Pool 5 suffers somewhat less from sedimentation than does Pool 4, but neither Pool is any longer a wholly favorable environment for mussels, at least in its main channel portion.
>
> The overwhelming domination of especially the Pool 5 data by juveniles, notably *Truncilla donaciformis* (whose discussion

see, below), is the best available evidence (Exhibits 66 and 67) of the superiority of the Pool 5 mussel fauna. Ancillary evidence appears in comparisons among historical, recent, and current information; the respective totals are 15, 15, and 13 species (Exhibit 65). These figures suggest that the Pool 5 fauna has changed little during the past century. However, the total number of the species that have ever been found in this Pool is at least 25 (see Exhibit 65). At no one period of time, then, has more than two thirds of the cumulative fauna been found. If one assumes comparable sampling pressure and record-keeping during those periods, he must conclude that mussels have always been hard to find in Pool 5 (i.e., population sizes have been low). Perhaps the truth is not only that this Pool is not "any longer" (above) congenial to mussels, but also that it has never been so, at least in post-Columbian times.

This last point is strengthened by the fact that Grier (1922) mentioned only a single mussel bed in Pool 5 that had supported commercial harvest. This bed was near Minneiska, Minnesota. The bed near Alma, Wisconsin, noted by Grier may have extended into what is now Pool 5. The Academy found no trace of either bed.

Scarcely 15 RM in length, this is a short Pool, most of which has been rather heavily dredged prior to and during the 9-Foot Navigation Channel Project; specifically, most of this intensively maintained reach was almost perennially dredged during the 39-year period 1934 through 1972 (USACE, 1974b). Consequently, the Corps gave surveillance of this Pool a high priority in 1977, and the Academy surveyed most of it by examining two extremely lengthy Sites. As noted above, the meager results were interpreted as evidence that Pool 5 is not hospitable to mussels. These results are entirely consistent with those for the additional Pool 5 Sites studied in 1978.

The Locks and Dam 5 Culvert Construction Site scarcely figures in the preceding remarks because of its unique character (see below).

41. Locks and Dam 4 Lower Approach (Exhibits 39, 138, 201, 226)

Thirteen juvenile mussels were taken at this Site. Light dredging occurred here as recently as 1976.

42, 43. Mule Bend and Head of Island 42 Bank Repair (Exhibits 40, 139, 201, 226)

Mule Bend had experienced minor dredging in comparison with that at downstream Pool 5 Sites (USACE, 1974b; see

Fuller, 1978b) prior to heavy dredging during the period 1974 through 1979.

Three juvenile mussels were taken at Mule Bend; no living mussels were found at the associated bank-repair site.

44. West Newton (Exhibits 41, 140, 201, 227)

Fuller (1978b) reported on the 1977 field work:

> Viewed from upstream, the West Newton Site has the shape of a Y. The right (western) fork lies in the channel and consists only of an impact zone that terminates at the head of the Weaver Bottom Complex Site. The left (eastern) fork, however, does not end at the latitude of the beginning of the Weaver Site, but proceeds down Pomme de Terre (Belvidere) Slough for the additional mile below the impact zone that is specified in the Scope of Work...Now, near the upper end of this one-mile reach, Roebucks Run passes from the Weaver Site into Belvidere Slough. Data gained below this confluence could be ascribed to either Site, but West Newton has been chosen because Belvidere Slough is much larger than Roebucks Run and is assumed to exert by far the greater influence below their confluence. Here is an example of the situation in which a reach that is by definition part of one Site is considered environmentally part of another. (This situation recurred at the Dallas Island Site in Pool 19 (below).) The unfamiliar reader can better follow this discussion with aid from USACE (1975).
>
> Disposal bank sampling at West Newton revealed 10 naiad species. None is federally protected. None was represented by more than a few individuals. The latter point supports the conclusion that adult populations are sparse in Pool 5.

This last point is in sharp contrast to Grier's (1922) emphasizing the excellent mussel beds in Pomme de Terre (Belvidere) Slough and West Newton Chute. On the other hand, it should be noted that the WDNR survey found somewhat more adult mussels than did the Academy, including the rare *Pleurobema rubrum*, Pink Pigtoe (P. Thiel, WDNR, La Crosse, personal communication).

Light to moderate dredging has occurred in the vicinity of the West Newton Site as recently as 1979. The Academy has no evidence that this dredging has had an adverse impact on mussels; in fact, this is highly unlikely except perhaps for any instances of two-step disposal.

The description of the extent of this Site is now illustrated by a map (Exhibit 227).

45. Weaver Bottoms Complex (Exhibits 42, 141, 201, 228)

Fuller (1978b) reported that:

> Work at Fisher Island within the Complex had taken place in May 1977 (Fuller, 1977a), but added nothing novel to the September |1977| results for this Site.

46. Locks and Dam 5 Culvert Construction (in part) (see Pool 5A, below) (Exhibits 43, 142, 201, 202, 229)

As Fuller (1978b) reported:

> This Site is unique in the Study Area, but not because part of it lies "in" Pool 5A (which see, below). It consists of limited areas above and below the Locks and Dam 5 earthen dam in the vicinity of a point where a culvert through the dam is proposed. The upper portion of the Site lies in Pool 5. Few mussels were found there. They were dominated by *Amblema plicata*. Significantly, in this area of stable riverbed more species were found than elsewhere in the Pool (Exhibits 66 and 67), where predominantly shifting sand floor was encountered.

Pool 5A (Exhibits 143, 202)

Like Pool 5 (above), this UMR reach is short (hardly 10 RM in length). Several of the Sites studied by the Academy have been dredged during most years from 1934 through 1972 (USACE, 1974b) and thereafter through 1978 or 1979. However, the amounts of dredged material and the lengths of the cuts have been minor, so Corps channel-maintenance :edging has been rather slight, but very persistent. This type of activity probably has contributed to naiad extirpation in the navigation channel, where almost constant shoaling of the moving bedload that necessitated dredging probably had already created a streambed habitat unsuitable for mussels.

Recent information about mussels in Pool 5A can be gained from literature concerning the historical record, Fuller's (1977) results of a May 1977 cursory surveillance, the Academy surveys in 1977 and 1978, and some recent Wisconsin Department of Natural Resources records (T.E. Larsen and P. Thiel, WDNR, La Crosse, personal communications). Data drawn from these sources indicate an impoverished Pool 5A naiad fauna in recent years and in even earlier times.

46. Locks and Dam 5 Culvert Construction (in part) (See Pool 5, above) (Exhibits 43, 142, 201, 202, 229)

As previously reported (Fuller, 1978b):

Part of this Site lies in Pool 5 (which see, above). The part "in" Pool 5A actually is in a swamp on this Pool's flood plain near the eastern end of the Locks and Dam 5 earthen dam. No trace of mussels, living or dead, was found in this swampy area.

47. Locks and Dam 5 Lower Approach (Exhibits 44, 144, 202, 229)

Few living mussels (all of common species) were found at this Site.

48, 49, 50. Island 58, Island 58 Bank Repair, and Fountain City (Exhibits 45, 145, 202, 230)

The two channel-maintenance portions of this mile-long reach lie in that portion of Pool 5A that has been most intensively dredged. The dredging history and the length of this reach are as long as those of any others, and the dredging frequency and the amount of dredged material within the reach are the greatest in this Pool (USACE, 1974b). Moderate dredging was conducted at the Island 58 Site during the period 1975 through 1979.

Only 38 living mussels, representing six species, were found in this reach. These few specimens, none of which is of exceptional interest, reflect a zoologically stricken Pool, at least in terms of naiades.

51. Fountain City Service Base (Exhibits 46, 146, 202, 230)

No mussels, living or dead, were found at this Site.

52. Fountain City Small Boat Harbor (Exhibits 47, 147, 202, 230)

Nine living mussels, representing four common species, were taken here. These results differ profoundly from Grier's (1922) report of an excellent commercial mussel bed at or near Fountain City.

53, 54, 55. Betsy Slough, Betsy Slough Bank Repair, and Wilds Bend (Exhibits 48, 148, 202, 230)

These three Sites are so nearly contiguous that they were treated in the field and are treated in this report as a continuous unit.

The (lengthy) UMR reach in question exhibited an extremely impoverished naiad fauna in 1978. This result is consistent with the fact that the extent of dredging in this reach

has been second only to that of the Fountain City area (above). There were no noteworthy taxon-specific mussel discoveries in the reach. Grier (1922) reported that by 1920 the great bed near Wilds Landing had already been destroyed, presumably by bedload directed shoreward by wing dams.

56. Locks and Dam 5A Upper Approach (Exhibits 49, 149, 202, 231)

Only four living mussels were recovered at this Site, none of which is exceptional in the UMR. The presence here of the Lilliput (*Carunculina parva*) serves as a reminder that this species (especially as the juvenile) is more widespread in the UMR than hitherto had been supposed (see Fuller, 1978b).

Pool 6 (Exhibit 150, 202)

Like Pools 5 and 5A (above), this reach is short (not quite 15 RM in length); in comparison to Pools 5 and 5A (and others above them), Pool 6 has a history of lesser dredging. This suggests that Pool 6 is less affected by Chippewa bedload. Consequently, it was to be expected that the mussel fauna of this Pool would prove to be superior to those farther up the Mississippi. This expectation is supported by the 1978 results (the Academy did not definitively study Pool 6 channel-maintenance sites in 1977 or 1979).

By comparison with the historical record, there appears to have been a decline in the abundance of mussels in this Pool; however, there is a question about whether all types of habitats have been explored in previous studies. The Academy's 1978 investigation of mussel habitats in Pool 6 progressed well beyond what was accomplished during the very cursory treatment the previous year (Fuller, 1977), resulting, for instance, in the addition of new species to this Pool's modern list of mussels.

57. Locks and Dam 5A Lower Approach (Exhibits 50, 151, 202, 231)

Only one living mussel was found here. This is another indication that heightened human activity near a lock-and-dam installation probably is inimical to naiad life. Light dredging took place at this Site as recently as 1976.

58. Winona Commercial Harbor and Small Boat Harbors (Exhibits 51, 152, 202, 232)

Only eight living mussels were found among these harbors. The Small Boat Harbor is unusual among UMR harbors in the St. Paul District in that it has a history of high-frequency dredging. For example, a small quantity of material was removed in each of four years during the period 1973

through 1979. There doubtless is a stong positive correlation between this record and the near-absence of mussels from this harbor.

59. Winona Lower Railroad Bridge (Exhibits 52, 153, 202, 232)

A single living juvenile mussel was found here.

This Site has experienced more Corps dredging than any other in Pool 6 (USACE, 1974b). Moderate quantities of material were removed as recently as 1976.

As part of a separate project, the Academy conducted mussel surveillance near this Site in 1979 (Fuller, 1979c).

60. Gravel Point (Exhibits 53, 154, 202, 232)

This Site lies in a reach of low channel-maintenance activity, especially in contrast to the Corps' (USACE, 1974b) record of Pool 6 dredging in the vicinity of the Winona Lower Railroad Bridge (see just above); dredging at this Site was minor throughout the period 1934 through 1972 (USACE, 1974b).

The relic bed at Homer, Minnesota, was found to extend upstream along bank protection approximately to the lower limit of the 1978 Gravel Point Site (see Fuller, 1977). Brailing this bed produced a very old, but living Ebony Shell, *Fusconaia ebena*, which is almost extinct in the UMR. This is the only such record for the St. Paul District in recent years.

The mussel fauna at the Gravel Point Site is the only one known in the main channel borders of Pool 6 that even remotely resembles the great mussel beds that Grier (1922, 1926a) recorded in the Winona vicinity. In 1920 and 1925 there was a flourishing bed in the navigation channel beneath the Winona railroad bridge of that day, plus another in Straight Slough above town. Sixty years ago the Winona reach evidently represented a turning point in the quality of UMR mussel life, just as it does today. The extensive beds of young mussels in the overbank habitats opposite Winona are the modern analog of the adult beds of the past. It is probable that then, as now, the adverse effects of moving bedload and/or pollution had significantly abated shortly upstream from Winona. The town lies at the head of the Recovery Zone of modern naiad distribution in the UMR; in effect, it apparently has for many years.

Pool 7 (Exhibits 155, 203)

Like certain Pools lying just upstream, this one is short (scarcely 12 RM in length), but its bedload is much less than theirs. Although most of Pool 7 has a history of recurrent

dredging, its dredging activity has been minor in comparison to that of, say, Pool 4 in terms of frequency, quantity of bedload, and length of cut (see above and USACE, 1974b). The comparison of Pools 4 and 7 is instructive because it demonstrates abatement of the Chippewa Zone of adverse impact on UMR mussels by bedload (discussed above). On the other hand, Pool 7 does retain some bedload problem, and mussel surveillance of this Pool has not been exhaustive. No studies were conducted in 1977 or 1979; only four Sites were studied in 1978, of which only two were channel-maintenance Sites. Further biotic surveillance of this Pool is appropriate.

Fuller (1978b) reported that the data from previous studies of Pool 7:

> ...show a definite increase in the number of mussel species since the time of Dawley's (1947) list for "Dresbach" (in Pool 7), especially inasmuch as Marian E. Havlik's (personal communication) most "recent" records can be considered nearly or quite current for 1977. The apparent increase has been caused probably by greatly increased local interest in naiades (notably Havlik's). This suggests that recorded declines in certain other Pools are more apparent than real (Pools 4 and 6 are good examples). However, it is well to remember that the context of these remarks is number of species, not the overall well-being of the mussel community.
>
> In addition to Finke's (1966) records for living *Lampsilis higginsi* in Pool 7 during 1965, M.E. Havlik (personal communication) has found this species' dead shells on dredged material banks. The Corps' responsibility for these deaths is indicated.

61. Locks and Dam 6 Lower Approach (Exhibits 54, 156, 203, 233)

There has been frequent, but not recent channel-maintenance activity in the vicinity of this Site (USACE, 1974b). The Academy found few living mussels here in 1978.

62. Richmond Island (Exhibits 55, 157, 203, 233)

This Site lies within that reach of Pool 7 that has experienced the most intensive Corps channel-maintenance dredging (see USACE, 1974b). A moderate quantity of riverbed material was removed as recently as 1975. The Academy's rather species-poor samples are thus understandable. Nevertheless, the Richmond Island Site exhibited an apparently competent mussel community, which was dominated (in 1978) by Pimpleback (*Quadrula pustulosa*) and Hickorynut (*Obovaria olivaria*). This was the Academy's northernmost observation of the Hickorynut as an important faunal element.

63. Queens Bluff (Exhibits 56, 158, 203, 233)

This has been a low-frequency dredging Site (USACE, 1974b). The Academy's samples include a preponderance of Threeridge, *Amblema plicata*. This is the northernmost 1978 Site at which this classic UMR domination of the mussel fauna was apparent. Dominance was weakly shared by *Quadrula pustulosa*. Another interesting aspect of this Site's naiad fauna was a single adult of the White Heelsplitter, *Lasmigona complanata*, which is nearing extinction in the UMR.

64. Locks and Dam 7 Upper Approach (Exhibits 57, 159, 203, 234)

Channel maintenance at this Site has been very minor (USACE, 1974b). However, as at any point on the UMR that experiences heavy waterway traffic and its associated influences (e.g., petrochemical pollution), this Site was not expected to and did not support a robust naiad community. However, the numbers of living specimens (29) and species (7) did exceed expectations, and therefore it appears that other environmental conditions supporting mussels in Pool 6 are sufficient to offset the adverse influences of heavy waterway traffic.

Pool 8 (Exhibits 160, 204)

Corps dredging in this Pool has been light, except near Brownsville, Minnesota (USACE, 1974b), and appears to have had little or no impact upon the modern mussel community. At the lower Sites, this community achieves a variety of species, including some rarities, that is far superior to that at sites dredged no more heavily. The lower Pool 8 fauna is the uppermost evidence in the UMR mussel Recovery Zone of sharp improvement in the variety of adults, as well as the juvenile portion of the community.

The Academy studied 10 Sites in this Pool, from which 23 living species of mussels were obtained. As Fuller (1978b) reported:

> ...other current, some historical, and many recent records are available, as well. The current and recent species totals are very nearly the same, and both greatly exceed the sum of historical data. The discrepancy is surely caused by a dearth of relevant historical records. The Dawley (1947) study, for example, includes no records for Pool 8, and there are no studies that thoroughly examine this Pool's naiad fauna. The greatest loss of information is that, in synopsizing the results of the Ellis survey, the van der Schalies (1950) wrote from an essentially biogeographic point of view and provided no species lists (though a few notes) to accompany their list of Ellis' positive stations. In fact, there were only two (possibly three) such stations in Pool 8..., but not any of the relevant species data, however few

they may be, have been published. Moreover, the recent study by Coon et al. (1977) on the 1975 naiad fauna in Pools 8, 9, and 10 does not provide Pool-specific information.

The Coon study is intended to compare recent mussels of these three Pools with the very similar area ("Zones III and IV") of the van der Schalies' (1950) paper. Comparison of the results of Coon et al. to Ellis' shows a net loss of nine species from Pools 8, 9, and/or 10 during the intervening 40-odd years. The change is not surprising: for example, two of the nine (*Propterá capax* and *Lampsilis higginsi*) are now federally Endangered, and several of the others are very rare.

On the other hand, disappointment at this trend must be tempered somewhat by the evidence of the current fauna as revealed by combining the data in Exhibits 72, 75, and 79. In 1977, 28 mussel species were found alive in the Upper Mississippi River reach that consists of Pools 8, 9, and 10. Refusal (as in this report) to recognize *Lampsilis fallaciosa* 'Smith' Simpson as other than a form of *L. teres* means that the corresponding totals realized by Coon et al. (1977) and in Ellis' work are 21 and 29, respectively. Among the current 28 are several species not found by those workers, and Marian E. Havlik (personal communication) has found a few more in Pool 10 so recently that they are reasonable addenda to the 28. In terms of numbers of species, then, the modern fauna in this reach compares surprisingly well with that of nearly 50 years ago. Aside from the almost unarguable loss of a few species from these Pools in the meantime, the major changes that have occurred are matters of community structure. The more notable of these are considered in the species accounts below.

65. <u>La Crosse Railroad Bridge</u> (Exhibits 58, 161, 204, 235)

This Site lies within a UMR reach that has experienced repeated, although not especially intensive Corps channel-maintenance dredging, from 1936 to 1970 (USACE, 1974b) and through 1976. This dredging, however, was infrequent after the early years of the 9-Foot Navigation Channel Project and involved short dredge cuts and small amounts of dredged material.

While this dredging activity and the presumably causal bedload have not been severe, the attendant mussel community is in only fair condition: 26 living specimens were taken in 1978, representing six species. The only noteworthy fact about this community is the finding of a single, adult Mapleleaf (*Quadrula quadrula*).

66. Hingen Island Bank Repair (Exhibits 59, 162, 204, 236)

Only a few mussels were taken here; most are *Obovaria olivaria*, which in Pool 8 begins to become an important UMR faunal element.

67, 68. Sand Slough and Sand Slough Bank Repair (Exhibits 60, 163, 204, 236)

These Sites pose a problem in nomenclature because the proposed bank repair actually would not be in Sand Slough at all, but along a nameless island some distance away. The location of the repair is indicated in Exhibit 236.

The Sand Slough Site itself has a history of light to moderate dredging from 1936 through 1969 (USACE, 1974b). This reflects a light to moderate amount of moving bedload over the years, which suggests that a good mussel fauna is possible there. The disappointing nature of the Academy's samples indicates that some other adverse factor exists here (such as the local erosion that is evidenced by the need for bank repair).

Though small and unremarkable generally, the mussel samples include the southerly elements *Quadrula quadrula* and *Obovaria olivaria*. (Note that considering these species "southerly" describes their modern situation; the original ranges of both species were much more extensive.)

69. Root River (Exhibits 61, 164, 204, 237)

Dredging has occurred here only twice (1936 and 1960) within the period of public record, and in these years it was only moderate (USACE, 1974b). Bedload clearly is not a problem here, yet the mussel community is very poor. Perhaps there is an unidentified local adverse point source, such as unfavorable water quality below La Crosse, Wisconsin, or agricultural runoff (perhaps including biocides) introduced by the Root River itself.

70. Picayune Island (Exhibits 62, 165, 204, 237)

Corps dredging at this Site has been minor. It was dredged by the Corps in 1936, 1969 and 1972; small quantities of material were removed on each of these occasions (USACE, 1974b). Light dredging also took place as recently as 1973. The Academy's mussel samples at this Site were very poor.

71, 72. Above Brownsville and Brownsville (Exhibits 63, 64, 166, 167, 204, 237, 238)

As previously reported (Fuller, 1978b):

Being contiguous and environmentally similar, these two Sites are discussed essentially as a unit.

Commencing in 1940 and continuing through 1972, the Corps conducted moderately extensive dredging at either Site or both during most years (USACE, 1974b). The small numbers of dead shells on the historical dredged material banks indicated that the dredging had killed few mussels over the years. This inference is in accord with the character of the current fauna of this reach, which is rather species-poor and in 1977 consisted largely of juvenile *Carunculina parva*. As was true of so many Sites, the only common adults were *Amblema plicata*.

After the Academy had examined the Brownsville Site and found no trace of Endangered species, the Corps renewed dredging there. Subsequently, there was discovered on a fresh disposal bank a newly deceased mussel that Marian E. Havlik and David H. Stansbery (Ohio State University, personal communication), as well as the Principal Investigator, believe to be *Lampsilis higginsi*.

This document is not a proper place to debate the merits of the Endangered Species Act of 1973. Nevertheless, one conclusion that should be drawn from this incident is painfully clear: in spite of the undeniable good intentions of the Act, there still exists no device whereby the inappropriately trained person can rapidly learn to identiy Upper Mississippi River mussels in order to prevent his getting into legal difficulties as a result of inadvertent "harassment" of an Endangered or Threatened species.

In its lower reach the Brownsville Site forks. The left (eastern) limb follows down the part of the main channel that is known as Cook Slough. The right limb quickly becomes unbrailable shallows among stump fields. This area supported much submerged vascular vegetation, which was characteristic of most slack water at both Sites.

Most of each Site, however, consisted of slightly deeper water over sand. The copious bedload of this reach has been responsible for the ongoing dredging history and, no doubt, for the paucity of mussels, especially adults (see *Truncilla donaciformis*, below).

Corps dredging data for these two Sites has been brought up to date since this excerpt was prepared. The Above Brownsville Site was very heavily dredged in 1973, and relatively light dredging was conducted in subsequent years, most recently in 1978 (as noted above). The Brownsville Site was moderately dredged in 1973.

The need for a device that the layman (and the inexperienced scientist) can use to identify UMR naiades has been met by the mussel poster that the Academy developed for the Corps and the Fish and Wildlife Service (Fuller et al., 1980) and by the identification key (Appendix E).

73. Crosby Slough (Exhibits 65, 168, 204, 239)

This Site experienced channel-maintenance dredging only in 1950 and 1963; Corps dredging has been infrequent and low-volume (USACE, 1974b).

The 1979 mussel community was poor in number and variety of species and was dominated by the typical UMR assemblage of *Amblema plicata*, *Quadrula pustulosa*, and *Fusconaia flava*.

74. Warners Landing (Exhibits 66, 169, 204, 239)

Dredging was conducted here only in 1963, when a small quantity of material was removed (USACE, 1974b). In comparison to most channel-maintenance programs in the St. Paul District, this is very slight dredging indeed and possibly has a bearing on the good quality of the mussel community at this Site. The samples consist of 291 individuals representing 18 species, including *Quadrula quadrula*, *Q. nodulata*, and *Lampsilis teres*. Probably because of adverse water quality, these three species today have southern distributions in the UMR. Finding them in Pool 8 was unexpected and is very encouraging. Extensive pollywogging at Warners Landing revealed *Proptera alata* in unexpectedly large numbers (though hardly in great abundance), plus a few *L. radiata siliquoidea*, which has become extremely rare in the UMR. These, also, are encouraging discoveries, especially because *L. r. siliquoidea* was not anticipated anywhere in the study area.

Pool 9 (Exhibits 170, 205)

Dredging in Pool 9 has varied widely in terms of volume, frequency, and recency. As in Pool 8, the pattern apparently has little or no bearing on the consistently rather poor mussel community observed by the Academy at the 15 nominal Sites. On the other hand, Pool 9 shares some of the marked increase in rare mussel taxa that occurs in lower Pool 8.

As Fuller (1978b) noted:

> The mussel data available from this Pool are sparse.... Finke (1966) and Perry (1978) provided some recent records; Ackerman (1976), none....

75, 76. Island 126 and Head of Island 126 Bank Repair (Exhibits 67, 171, 205, 240)

The history of channel-maintenance dredging in the vicinity of Island 126 divides into two parts (USACE, 1974b). First there was a period of high-frequency, low-volume removal of riverbed material early in the 9-Foot Navigation Channel Project.

Dredging became less frequent, but greater volumes were involved. This is an unusual pattern, but still indicative of intense activity. Perhaps as a result, the local mussel community was very poor in 1978, and the bank protection part of the Site contributed nothing to the records for the whole.

<u>77, 78. Twin Island and Head of Twin Island Bank Repair (Exhibits 68, 172, 205, 240)</u>

Dredging of moderate volumes was almost perennial in the Twin Island reach through the Sixties (USACE 1974b) and continued through 1976. Throughout the Site, including the Bank Repair section, the mussel community was extremely poor in 1978.

<u>79. Below Twin Island</u> (Exhibits 69, 173, 205, 240)

Unique among channel-maintenance Sites in the study area, Below Twin Island has no history of bedload removal (USACE, 1974b). It was surveyed because its contiguity with the often-dredged Twin Island Site (immediately upstream) suggests that it eventually will experience some dredging.

The mussel communities at both these Sites are extremely poor in spite of their very different dredging histories. This is a dramatic example of why it must not be assumed that dredging history solely determines mussel welfare.

<u>80. Battle Island</u> (Exhibits 70, 174, 205, 241)

On an average of about every third year during the entire history of the 9-Foot Navigation Channel Project, this Site experienced channel-maintenance dredging of variable frequency and volume (USACE, 1974b), which persisted through 1973. This is a pattern of rather regular, but not intensive dredging. In spite of occurrence of the rare *Elliptio dilatata*, the known mussel fauna (10 species, but few individuals) must be considered poor.

<u>81. DeSoto</u> (Exhibits 71, 175, 205, 242)

A large dredge cut was made in 1937, but thereafter dredging here was very rare (USACE, 1974b). The mussel community is poor in numbers of individuals, but includes living representatives of at least 11 species, including the rather rare *Elliptio dilatata* and *Arcidens confragosus* and the very rare *Pleurobema rubrum*. During this study it was unusual to find any of these species north of Pool 8.

82, 83. Above Indian Camp Light and Mouth of Hummingbird Slough Bank Repair (Exhibits 72, 176, 205, 243)

Fuller (1978b) noted that Site 82

> ... was dredged rather extensively in 1937, but had not been revisited through 1972 (USACE, 1974b).
>
> The Site included upper Winneshiek Slough, where mussels were a bit more common along riprap above the Iowa state route 82 bridge than they were elsewhere in the Site.

The Bank Repair reach had been routinely surveyed in 1977. It was examined more minutely in 1978, but no mussels were found.

84. Indian Camp Light (Exhibits 73, 177, 205, 243)

As reported by Fuller (1978b):

> The mussel fauna here was exceptionally poor. However, Corps dredging, only occasional from 1936 through 1972 (USACE, 1974b), could hardly have been at fault.

This Site was additionally dredged in 1973, 1974, and 1978. The total quantity of riverbed material removed was moderate.

85. Lansing Upper Light (Exhibits 74, 178, 205, 243)

Fuller (1978b) reported the following:

> Much longer than the Above Indian Camp Light Site, this one supported a mussel fauna that was proportionately even more impoverished.
>
> Corps dredging took place almost the length of the Site in 1937, but thereafter through 1972 was intermittent and confined essentially to the 1977 impact zone (USACE, 1974b).

This Site was additionally dredged in 1973, 1974, and 1978. The total quantity of riverbed material removed was great.

86. Lansing Small Boat Harbor (Exhibits 75, 179, 205, 243)

In 1978 mussels were almost non-existent at this Site, which apparently has no recorded dredging history (see USACE, 1974b). There is little reason to assume historical mussel records at this Site, because the Harbor was partially created by excavating the riverbank.

The UMRCC survey sampled at RM 663.0 (Perry, 1979); the exact sampling point may be within the bounds of the Lansing Small Boat Harbor Site.

87. Atchafalaya (Exhibits 76, 180, 205, 244)

This Site's dredging history is limited to moderate dredging in 1970 (USACE, 1974b). Few living mussels were found, but they included *Quadrula quadrula*, *Q. nodulata*, *Megalonaias gigantea*, and *Lampsilis teres*, none of which is common in the St. Paul District.

88. Crooked Slough (Exhibits 77, 181, 205, 245)

The Corps dredged here twice, moderately, and neither occurrence was recent (USACE, 1974b). The Academy found few mussels, but these included *Quadrula nodulata*, rather rare in Pool 9.

89. Locks and Dam 9 Upper Approach (Exhibits 78, 182, 205, 246)

The Site has no recorded dredging history (see USACE, 1974b), but the Academy's mussel samples were very poor. This is usually the case around locks and dams, which are places of intensive human activity. On the other hand, the uncommon *Arcidens confragosus* was found here.

Pool 10 (Exhibits 183, 206)

Occasional channel-maintenance dredging in this Pool began in 1937 and continued through 1972 (USACE, 1974b) and, to a lesser degree, beyond. This dredging appears to have done the Pool 10 mussel fauna no widespread harm. The far more limited bank-repair dredging in the Pool seems not to have harmed mussels.

The mussel fauna of Pool 10 evidently is the best in the St. Paul District, and the community around McGregor, Iowa, and Prairie du Chien, Wisconsin, is the finest mussel assemblage in the District.

In view of the inferences (above) about Pools 8 and 9, it is unlikely that there is a strong positive correlation between the nature of the modern mussel fauna and the history of dredging in Pool 10.

The work of the Ellis survey in 1930 and 1931 (van der Schalie and van der Schalie, 1950), the UMRCC survey (Perry, 1979), the WDNR survey (P. Thiel, WDNR, La Crosse, personal communication), and the Academy survey (Fuller, 1978b, and the present report), plus some published studies (notably Havlik and Stansbery, 1978), have provided an unusually thorough understanding of the mussels of this Pool. Modern distributions are imperfectly known, but it is clear that changes have occurred since the earliest study (i.e., Baker, 1905). Most of these

changes have been negative, but there have been far fewer of them than has been the case in upstream pools.

90. Locks and Dam 9 Lower Approach (Exhibits 79, 184, 206, 246)

This Site proved to be an exception to the general pattern that areas in the immediate vicinity of UMR Locks and Dams are extremely unproductive of mussels (see Fuller, 1978b, and elsewhere in the present report). It appears that at most such areas, any existing populations were destroyed during these installations' construction some 40 years ago and that recolonization has since been prevented by concentrated, more or less continuous disturbances (e.g., maintenance, boat traffic).

The Academy's samples from this Site were quite good, being composed of 100 individuals and 11 species. Although heavily dominated in the classic pattern (i.e., by Threeridge, *Amblema plicata*), this assemblage included some noteworthy items. *Obliquaria reflexa* was common, *Obovaria olivaria* occurred, and there was a specimen of *Anodonta imbecillis*. The most interesting occurrence is two Wartyback, *Quadrula nodulata*, which is a distinctly southern element in the UMR naiad fauna. Indeed, these two Wartyback are almost the northernmost recent records of this species in the river.

This remarkable mussel community may be possible because of the proximity of great beds in the vicinity of Hay Point, just downstream (see below and Fuller, 1978b: Hay Point Bank Repair). In fact, this site's fauna may be a remnant of those beds that survived construction of Locks and Dam 9, or, more likely, it may be a product of recruitment from them through transmittal by glochidial hosts. In any case, the mussel fauna below this installation is an extraordinary phenomenon, the more so because dredging has regularly occurred at this site, at least as recently as 1959, only 20 years ago (USACE, 1974b); two decades may be insufficient for development of the mussel fauna observed below Locks and Dam 9 in 1978.

91. Hay Point Bank Repair (Exhibits 80, 185, 206, 246)

As previously reported (Fuller, 1978b):

> Because it is of the construction variety, this Site was not being maintained in 1977, but dredging was to occur as part of the bank repair, so a definitive investigation was made.
>
> The Hay Point Site supports an excellent mussel community, whose focal point is two commercial beds (Exhibit [246]), long known to local folk (personal communications). Although greatly dominated by *Amblema plicata*, the fauna is species-rich.

The 1977 mussel surveillance at this Site included examination of part of the Opposite Harpers Slough Site.

92. Jackson Island (Exhibits 81, 186, 206, 247)

This Site's dredging history involves removal of small amounts of material during the period 1941 through 1969 (USACE, 1974b) and again in 1975. This history suggests that moving bedload has troubled mussels here very little. The Academy's mussel samples (over 100 specimens representing 12 species) therefore are not surprising (this is not one of the best assemblages, even in the modern, degraded UMR, but it is superior to most sites'). It can be inferred that water quality probably is good at this Site, because the minor dredging activity here may not adequately explain the good mussel fauna observed.

Noteworthy animals in these samples are *Quadrula quadrula*, *Q. nodulata*, *Obovaria olivaria*, and *Anodonta imbecillis*, plus one Rockshell, *Arcidens confragosus*, a species that is rather rare in the UMR (see Fuller, 1978b).

93. Mississippi Gardens (Exhibits 82, 187, 206, 247)

Previous Corps samples in this area had given the impression of a rich mussel fauna (R.J. Whiting, USACE, St. Paul District, personal communications). In comparison, the Academy samples, taken by brail in October 1978, were disappointing. The Principal Investigator suspected that a recent, seasonably cold period might have depressed water temperatures below the point at which mussels enter winter dormancy and respond poorly to the brail hooks. Trial brail drifts over the mussel beds in the East Channel at nearby Prairie du Chien revealed a 75% loss of expected catch at this well understood Site (previously investigated at length by the Academy over two seasons). The result was a joint Corps-Academy decision to terminate 1978 field work prematurely. The work was resumed in 1979.

In anticipation of returning to Mississippi Gardens the following year, the 1978 sampling data were discarded as being of highly questionable reliability. Unfortunately, the Site could not be re-examined in 1979, because of temporal constraints. The 1978 Academy sampling data had shown the usual UMR dominance by Threeridge, *Amblema plicata*, plus no sign of Endangered mussels. This information is dependable to a limited extent, but the Site probably should be resurveyed. Mississippi Gardens is an excellent example of a reach whose investigation could reliably be undertaken by Corps personnel if they were suitably equipped and, perhaps, advised. The Academy has helped the Corps to assemble the appropriate sampling gear, and several institutions, including the Academy, could provide an appropriately experienced malacologist to aid identification of Endangered

Species in the field at point of capture. The latter point is especially germane to surveillance of any site that is near a known location of an Endangered mussel. In the case of Mississippi Gardens, perhaps the last strong population of the Endangered Species *Lampsilis higginsi*, Higgins' Eye, is only a few RM downstream in the Prairie du Chien East Channel.

Mississippi Gardens was most recently dredged in 1976, when a moderate amount of riverbed material was removed.

94. Prairie du Chien East Channel (Exhibits 83, 188, 206, 248)

The Academy surveyed here in 1977, when Prairie du Chien East Channel was not a formal Site, because of the known presence of the Endangered Species *Lampsilis higginsi*, Higgins' Eye. During the 1977 examination hundreds of UMR naiad data were recorded (see Fuller, 1978b); they are involved in numerous Exhibits of the present document and greatly enhance understanding of unionid community structure at its best in the UMR. The Prairie du Chien East Channel mussel bed is generally regarded as the best developed mussel congregation in the St. Paul District.

In 1978 this congregation and its immediate vicinity comprised a formal Site; accordingly, the Prairie du Chien East Channel mussel bed was thoroughly studied (by brail). The Academy's 1977 and 1978 data for this Site are combined in Exhibit 188. This combined information almost encapsulates what is known about modern UMR naiad community composition.

This information was enhanced by the results of another instance of coordination among the Corps, the Fish and Wildlife Service, and the Academy: the UMRCC mussel biology workshop held at McGregor, Iowa, in late September 1978. During this workshop an enormous amount of brailing on the Prairie du Chien bed just across the river was conducted by attendees and is reflected in the present report.

In 1976 the East Channel at Prairie du Chien was heavily dredged. In the process, scores of living specimens of *Lampsilis higginsi* were accidently destroyed. Concern by the Government that such an error not recur led to the present study.

95. Prairie du Chien Commercial and Small Boat Harbors (Exhibits 84, 189, 206, 248)

This Site consisted of exclusively lentic waters with large quantities of submerged vascular vegetation, from which many juvenile mussels (of several species) were obtained. The Academy's sample is dominated by Lilliput, *Carunculina parva*,

which is not ordinarily brailed from the nearby East Channel mussel bed. This point exemplifies the value of backwater nursery areas to such a bed and to the UMR naiad fauna in general. It also illustrates the great value in surveillance studies, such as the present one, of examining certain habitat(s) that are associated with, though perhaps not part of, a formal Site.

96. McGregor (Exhibits 85, 190, 206, 248)

This Site has been dredged rarely (1937 and 1964) -- and then only lightly -- during the period of public record (USACE, 1974b). Mussel collections here were disappointing in comparison to the wealth of data secured from the great Prairie du Chien bed in the nearby East Channel. Related observations were made during surveillance of the McGregor, Iowa, commercial marinas (on behalf of the McGregor Waterfront Commission). An excellent bed of mussels was discovered by brailing immediately offshore from the McGregor marinas. This area is so close to the formal McGregor Site that its data are included in Exhibit 190.

97. Wyalusing Bend Light (Exhibits 86, 191, 206, 249)

Channel-maintenance dredging by the Corps at this Site is primarily a phenomenon of the 1940's and early 1950's, with a recurrence in 1969 (USACE, 1974b). This is a record of light dredging, and observed environmental characteristics appear suitable for mussels, yet few mussels were brailed in 1979. There is no apparent explanation for this paradox other than the suggestion that an unidentified adverse point source (e.g., bank erosion) may exist in the immediate vicinity.

Although the Academy's results are disapointing (at least in the context of the overall Pool 10 mussel fauna), there were a few interesting points. *Quadrula nodulata* and *Obovaria olivaria* recurred here. Also, single specimens of *Lampsilis radiata siliquoidea*, nearly extirpated from the UMR, and of the characteristically small-stream species *Strophitus undulatus*, Strange Floater, were taken.

98. Wyalusing (Exhibits 87, 192, 206, 249)

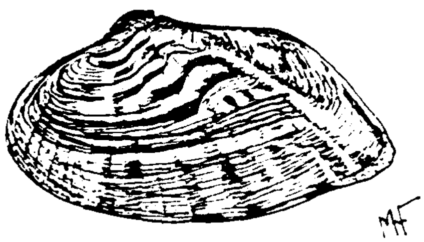
This Site's dredging history is essentially identical to that for Wyalusing Bend Light (see just above). Nevertheless, the Wyalusing Site's naiad fauna appears to be noticeably superior. The Academy's samples include several noteworthy species: *Quadrula quadrula*, *Q. nodulata*, *Obovaria olivaria*, *Arcidens confragosus* (represented by three individuals), and *Anodonta imbecillis* (see Exhibit 192).

99. McMillan Island (Exhibits 88, 193, 206, 250)

Dredging here has been infrequent and low-volume, and the last recorded instances were in 1970 (USACE, 1974b) and 1973. Perhaps reflecting this light dredging history, a good mussel sample of 225 living animals distributed among 18 diversified species was taken in the vicinity of McMillan Island. This total includes *Carunculina parva, Arcidens confragosus, Quadrula quadrula* (common), and *Q. nodulata* (very common), all infrequently encountered in the St. Paul District. As at the Warners Landing Site (above) in lower Pool 8, shallow-water pollywogging over hardpack sand and muddy sand revealed living examples of the rare *Lampsilis teres* and *L. radiata siliquoidea.* The UMRCC mussel survey sampled at RM 617.0 (Perry, 1979), which lies downstream from the McMillan Island Site.

100. Locks and Dam 10 Upper Approach (Exhibits 89, 194, 206, 251)

The mussel fauna here is superior to those near most locks and dams. *Quadrula nodulata* (fairly plentiful) and *Q. quadrula*, as examples, were taken; neither is very common in the St. Paul District. There apparently is no recorded dredging history at this Site (see USACE, 1974b).



Fawnfoot (juvenile)

Truncilla donaciformis (Lea)

DISCUSSION

Species-Group Mussel Taxa

In the corresponding section of the Academy's previous report (Fuller, 1978b), various aspects of the natural histories of Upper Mississippi River (UMR) naiades were discussed. This portion of the present report updates the discussions of those taxa for which significant new information has been provided by recently published literature and/or the results of the Academy's 1978 and 1979 field work in the St. Paul District. This new information may be divided into three categories: understanding of larval hosts, physical habitat, and geographic range.

Most of the new information on larval hosts comes from a paper by Stern and Felder (1978), in which numerous correlations between UMR mussels and their glochidial host fish(es) are reported, for the first time in some cases. These recent host-parasite records involve six fishes: *Notemigonus chrysoleucas* (Mitchill), Golden Shiner (Cyprinidae); *Gambusia affinis* (Baird and Girard), Mosquitofish (Poeciliidae); and several Centrarchidae: *Lepomis cyanellus* Rafinesque, Green Sunfish; *L. gulosus* (Cuvier), Warmouth; *L. macrochirus* Rafinesque, Bluegill; and *L. marginatus* (Holbrook), Dollar Sunfish. Two of these fishes are new to the history of host-parasite relationships between mussels and fish: *Gambusia affinis* and *Lepomis marginatus*.

The remaining new host record was noted by Parker et al. (1980). Such new data are of the greatest importance in understanding mussel biology and in efforts to conserve the aquatic resource that mussels represent.

Evans (1969) studied glochidiosis in three species of UMR fish: Golden Redhorse, *Moxostoma erythrurum* (Rafinesque); Bluegill, *Lepomis macrochirus* (Rafinesque); and Walleye, *Stizostedion v. vitreum* (Mitchill). None was found in this redhorse, but the latter species were found infected. This confirms the rather well known value of these two fishes as glochidial hosts (Fuller, 1974, 1978b). Unfortunately, Evans identified none of the glochidia involved in his research. Several known UMR host fishes were identified by Parker (1979) as hosts of *Glebula rotundata* (Valenciennes). This mussel is most abundant in Louisiana, but extends somewhat northward in the Mississippi River basin. Like *Proptera purpurata* (Table 1a), it is an extra-limital, southern species, but, unlike *P. purpurata*, *G. rotundata* has yet to be recorded in the UMR.

The most important new data concerning UMR mussels' habitat (and, in some cases, geographical distribution) are derived from the Academy's 1978 investigations near Winona, Minnesota. Extensive beds of mussels in overbank shallows were discovered in the main channel border opposite Winona. This not only was the Academy's first discovery of major mussel recruitment in the UMR below the Twin Cities, but also provides important new information about the statuses of numerous mussel taxa.

Finally, new geographic distributional data about UMR mussels are evident in the remarks below.

Quadrula metanevra, Monkeyface

Several young Monkeyface were found by pollywogging the beds opposite Winona, Minnesota. These discoveries are especially heartening in view of the previous (and unchanged) impression (see Fuller, 1978b) that *Quadrula metanevra* is in very grave difficulty in the UMR. Also encouraging is the realization that strong naiad recovery from upstream adverse impact occurs as far upriver as upper Pool 6.

Quadrula fragosa, False Mapleleaf

This species was first recorded from the UMR in the vicinity of Davenport, Iowa (Tryon, 1865). As far as the UMR is concerned, *Quadrula fragosa* was largely (perhaps fully) ignored until a recent study (Havlik and Stansbery, 1978) included an historical record at Prairie du Chien, Wisconsin (Pool 10). This species was not included in the Academy's previous report (Fuller, 1978b). In the meantime, however, the Principal Investigator has examined subfossil Prairie du Chien specimens in the M. E. Havlik collection that had been identified as *Q. fragosa* by D. H. Stansbery. This material is conchologically distinct from *Q. quadrula*, the common Mapleleaf, with which *Q. fragosa* obviously has been consistently confused (Appendix E).

Accordingly, *Quadrula fragosa* is admitted to the UMR naiad fauna *at least* for the purposes of this report. This species is (and perhaps always has been) a rarity (D. H. Stansbery, Ohio State University, personal communication). On the other hand, it is obvious that no one has sought it among the thousands of purported *Q. quadrula* that have been taken from the UMR during recent years' mussel surveillance; perhaps *Q. fragosa* currently is being overlooked, just as it apparently was throughout most of this past century. In any event, nothing is known of the biology of this species in the UMR.

Cyclonaias tuberculata, Purple Pimpleback

Two living specimens were taken in 1978 from the UMR, where this species' extinction is imminent. One was secured by Wisconsin Department of Natural Resources personnel in a relic bed at Wabasha, Minnesota, in Pool 4 (P. Thiel, WDNR, La Crosse, personal communication). The other was caught by a commercial [illegible] in Andalusia Slough, Pool 16 (T. M. Freitag, USACE, Rock [illegible] District, personal communication).

Fusconaia ebena, Ebony Shell

A single living individual of this rarity, whose extinction in the UMR is imminent, was taken by the Academy in 1978 from a relic bed above Homer, Minnesota.

Megalonaias gigantea, Washboard

In 1978 and 1979 the Academy encountered even fewer Washboard than it had in 1977. This development lends further credence to the thesis (M. E. Havlik, Malacological Consultants, La Crosse, Wisconsin, personal communication) that, in at least the immediate future, harvest of this commercially valuable species should be prohibited.

Amblema plicata, Threeridge

The alternative to taking the Washboard (discussed just above) is restricting the commercial harvest of mussels to the Threeridge, an at least equally valuable species and one of the two most abundant in the UMR (see *Truncilla donaciformis*, below).

Uniomerus tetralasmus (Say), Pondhorn

This species was admitted to the Academy's previous report (Fuller, 1978b) on the strength of the excellent possibility that the Pondhorn occurs undetected in the UMR. After two more seasons' field study, during which no Pondhorn were found, this likelihood appears less. Consequently, *Uniomerus tetralasmus* has been removed from the Academy's "master list" of UMR mussels (Exhibit 1a).

Stern and Felder (1978) recently demonstrated that the fish *Notemigonus chrysoleucas* is a glochidial host of *Uniomerus tetralasmus*. This is the first time that a larval host of a member of this ecologically extraordinary genus has been identified (see Fuller, 1974, 1978b).

Pleurobema rubrum, Pink Pigtoe

Most workers (e.g., Fuller, 1978b) have consistently used *P. cordatum* for all members of this genus in the UMR. D. H. Stansbery (Ohio State University, Columbus, personal communication) believes that the taxon "*P. cordatum*" includes several similar, but consistently distinguishable species, two of which have been recorded from the UM: *P. sintoxia* (discussed immediately below) and *P. rubrum*.

Because of the historical and current taxonomic problems attending this complex, Fuller's (1974, 1978b) ecological notes on "*P. cordatum*" (and its putative glochidial hosts) must be considered suspect. In any event, most *Pleurobema* taken from the UMR in the last few years surely are *P. rubrum*. Such records are few, and it is fair to say that little or nothing sound is known of this species' biology in the UMR.

Taxonomic dissection of the inclusive concept *Pleurobema cordatum* requires revision of its vernacular name (Ohio River Pigtoe), as well. Stansbery (personal communication) proposed Pink Pigtoe as the common name of *P. rubrum*. This name has been adopted in the present report (Exhibit 1a).

Pleurobema sintoxia, Round Pigtoe

Recognition of this species is another product of Stansbery's (personal communication) revision of the *Pleurobema cordatum* complex. Apparently the only authentic UMR record of *P. sintoxia* is at Prairie du Chien (Havlik and Stansbery, 1978). Nothing further is known of this species' biology in this waterway except that it probably is extirpated.

Elliptio crassidens, Elephant Ear

The Academy secured no unequivocal specimens of *Elliptio crassidens* in 1978 or 1979. The Principal Investigator now questions his claims (in Fuller, 1978b) of finding this species in the 1977 study area. These putative *E. crassidens* might be only an unusual morph of a congener, *E. dilatata*, the Spike, which they greatly resemble. (Note that in the present report the 1977 records have been retained, very hesitantly, as originally issued.) Regardless of the resolution of this question, there can no longer be doubt that the Elephant Ear is nearly or quite extinct in the UMR.

Obliquaria reflexa, Threehorn

Impressive numbers of young Threehorn were found in the Winona nursery beds, especially for an upper river-lake (Pool 6), where the impacts of the Twin Cities and Chippewa Zones reasonably could be expected to remain influential. This supports the view (Fuller, 1978b) that *Obliquaria reflexa* is a physiologically durable animal that probably has always existed in the UMR at a low, but stable population level (perhaps because of a correspondingly low, but adequate level of recruitment).

Proptera laevissima, Pink Papershell

The populations of large and healthy individuals that the Academy found in 1978 at various Pool 4 sites above Red Wing, Minnesota, are meaningful in two major respects. First, this Pool's reputation of being nearly devoid of mussels (see, e.g., Fuller, 1978b) is partly in error; clearly, Pool 3 exhibits water quality superior to those of the Pools above. Second, the Principal Investigator's interpretation of *Proptera laevissima* as a hardy species, possibly expanding its ecological and geographical ranges in the UMR (Fuller, 1978b), is additionally supported.

Ellipsaria lineolata, Butterfly

A flourishing population of the Butterfly was found by the Academy in 1978 in uppermost Pool 20, immediately below Locks and Dam 19 at Keokuk, Iowa (Fuller, 1979b), during surveillance on behalf of a private-sector client. The population disappeared just above confluence with the Des Moines River a few river miles below Keokuk. This discovery of *Ellipsaria lineolata* is meaningful in several respects. First, it supports the interpretation (Fuller, 1978b) of the Des Moines River as a negative point source with respect to the Mississippi. Second, the high proportions of females and of gravid females in this population support Fuller's (1978b) contention that the Butterfly has survived at a low, but stable population level throughout much of its range because of high proportions of females and gravidity. Third, earlier optimism about this species elsewhere in the Mississippi River (Fuller, 1978b) is somewhat tempered by the limited distribution of the 1978 Keokuk population. This probably is the last surviving population that reflects this species' abundance when it was a fairly important commercial species. On the other hand, the WDNR survey found small numbers of Butterfly as far upriver as Pool 5A (P. Thiel, WDNR, La Crosse, personal communication).

Truncilla donaciformis, Fawnfoot

Because they are of small size, adult and young Fawnfoot rarely are caught by the beaded tines of the modern mussel brail, but these "hooks" commonly entangle the byssi of immediately post-metamorphic individuals. Consequently, records of juveniles dominate Fawnfoot data in surveillance conducted chiefly by brail (such as the Academy's on behalf of the Corps). Even so, the Academy's 1977 data were so plentiful as to justify the inference (Fuller, 1978b) that *Truncilla donaciformis* was second in abundance only to *Amblema plicata*, the Threeridge (discussed above), in the UMR.

In 1978, however, the great Winona nursery beds were discovered. Here all post-larval stages of Fawnfoot were sampled effectively by shallow-water collecting by hand. In these samples Fawnfoot were almost twice as plentiful as Threeridge. Should this ratio between the two species persist more or less throughout the UMR, *A. plicata* would be replaced as most abundant mussel in the waterway, and the Threeridge's role in commerce (as discussed above) could be altered.

The Fawnfoot's success surely depends to some extent upon its recorded glochidial hosts, the Sauger and the Freshwater Drum. However, other, less successful mussels (e.g., *Lampsilis higginsi*, discussed below) depend largely or solely upon these same fishes. Therefore, the ill fortune of these less successful species logically must be due in some measure to factors other than host availability (such as adverse water quality, excessive harvest, etc.).

Ligumia subrostrata, Western Pondmussel

Stern and Felder (1978) recently added the sunfish *Lepomis gulosus* to historical records of this mussel's glochidial hosts, which include *L. cyanellus* and *L. macrochirus* (see Fuller, 1974, 1978b).

Carunculina parva, Lilliput

Stern and Felder (1978) recently recorded the fishes *Lepomis gulosus* and *L. macrochirus* as glochidial hosts of Louisiana populations of *Carunculina texasensis* (Lea). These data are repeated here because, in view of the taxonomic uncertainty within *Carunculina*, *C. texasensis* and *C. parva* may well prove to be conspecific. In any case, several species, including these two *Lepomis*, have been recorded as hosts of *C. parva* (Fuller, 1974, 1978b).

This species was common in the Winona beds and at several other locations in the 1978 and 1979 study areas where shallow-water collections could be made. This supports the view (Fuller, 1978b) that the traditional characterization of the Lilliput as a UMR rarity is a misconception arising from its being consistently overlooked on account of its small size.

Lampsilis higginsi, Higgins' Eye

In 1977 and 1978, Higgins' Eye was found in the St. Croix River opposite Hudson, Wisconsin, and in the Mississippi off Prairie du Chien, Wisconsin. The latter material (several

specimens, some alive) offered no novel information, but the Hudson sample was informative on several counts. First, because the St. Croix was unusually low when the Academy team was there in 1978, hand collecting was both practicable and productive: almost a dozen specimens (the majority alive) were obtained, in contrast to the two living animals found in 1977. Second, finding so many living specimens of the Endangered *Lampsilis higginsi* always is encouraging, but especially so when (see Fuller, 1978b) it occurs within only a few meters of a longtime Corps channel-dredging site. Third, one of the 1977 specimens (a gravid female, unfortunately) died in captivity; autopsy revealed evidence of pathology. One 1978 specimen died likewise. The 1977 animal exhibited a tumor; the 1978 individual had multiple parasitic encystments. It is probable that both types of affliction were caused by infestation with a fluke (Platyhelminthes: Trematoda).

Anodonta imbecillis, Paper Floater

In addition to this species' previously recorded glochidial hosts (see Fuller, 1974, 1978b), several new ones have been reported by Stern and Felder (1978): *Gambusia affinis*, *Lepomis gulosus*, *L. macrochirus*, and *L. marginatus*. Another, *L. megalotis*, was identified by Parker et al. (1980).

Habitat Requirements

In the remarks that follow, the expression "habitat" is given a very broad construction: a mussel's habitat is considered to exhibit physicochemical, behavioral, and geographic factors. Physicochemical factors include (but are not necessarily limited to) current, water depth, streambed composition, and water quality; behavioral factors include larval hosts; and geographic factors include present range (often in sharp contrast to former range).

The remarks essentially are abstractions of Fuller's (1978b) characterizations, but in some cases are augmented by new information. Their scope is the Upper Mississippi River proper and observations of its mussel resource. Additional considerations (e.g., Endangered- or Threatened-Species status, jeopardized-species status in the Upper Mississippi River) play a part in the sketches of species-group taxa that follow.

Cumberlandia monodonta, Spectacle Case

The Spectacle Case is ecologically unusual. It is a lithophile and thus a rarity among naiades. On the other hand,

Stansbery (1966) recorded other habitats that this species exploits. Similarly, Fuller's (1978b) records and commentary indicate that in the Upper Mississippi River this species may flourish on or in wingdams (an essentially rocky habitat) or in adjacent muddy areas of the riverbed.

Fuller's (1978b) observations are based upon captures of Spectacle Case in Lake Keokuk (i.e., Pool 19), a river-lake (Coker, 1929) of the Upper Mississippi River, in which normal water depth commonly is as much as twenty feet, current ordinarily is sluggish, and streambed character is sedimentary. These characteristics sharply contrast with those of a stream in the Cumberlandian region (van der Schalie and van der Schalie, 1950) where *Cumberlandia monodonta* might be found. In streams of the Cumberlandian region the Spectacle Case ordinarily is found in shallow, rapid waters over a rock or gravel streambed.

Recent findings of *Cumberlandia monodonta* in the Upper Mississippi River suggest that this species is not characteristic of the "northern tier of states" (Sawyer, 1972), but is an essentially southern biogeographical element that has invaded the Upper Mississippi drainage during post-Wisconsin geological time. Accordingly, its overall rarity in the Upper Mississippi River, whence it has been recorded alive from only a few Pools, is consonant with its having been proposed as a nationally Threatened Species.

Like other unionid mussels, *Cumberlandia monodonta* is presumed to pass the larval stage of its life cycle on a vertebrate host. Unfortunately, no such host has been identified for this mussel (see Fuller, 1974). Identification of the primary glochidial host in nature of the Spectacle Case might do much toward rejuvenation of this jeopardized species.

Quadrula metanevra, Monkeyface

Formerly widespread and rather plentiful in the Upper Mississippi River, the Monkeyface is now a great rarity there and elsewhere in its original range. Nevertheless, there are recent records of this species alive in many UMR Pools, and, although the Academy's three seasons' results include few specimens, they represent numerous age-classes. Fortunately, *Quadrula metanevra* thus has not fallen below recruitment level in the Upper Mississippi. The most encouraging evidence is the 1978 discovery of some early juveniles in muddy main channel border shallows opposite Winona, Minnesota. However, this species appears essentially restricted to the great beds, perhaps simply because a rarity is most likely to be found where mussels are most plentiful. Therefore, to stipulate that the optimal substrate for Monkeyface (and most other species) is stable, viscous mud, commonly with an admixture of gravel (see Kaskie,

1971), is doubtless true, but surely does not fully characterize its habitat preferences. Protecting this animal thus requires more than a knowledge of its preferred substrate; rather, sound conservatory and management practices must be applied throughout the river. Moreover, *Q. metanevra* could be very well served by legal protection in the Upper Mississippi River valley states. Such protection would be of additional value because the species is as yet not a strong candidate for national listing as a Threatened or as an Endangered Species.

Quadrula fragosa, False Mapleleaf

Only recently recognized as a member of the UMR naiad fauna (Havlik and Stansbery, 1978) and recorded from only two localities, this species obviously has always been a rarity in this waterway and probably has been extirpated. Nothing is known about its Upper Mississippi River ecology. A vernacular name (False Mapleleaf) is introduced with this report.

Quadrula quadrula, Mapleleaf

Unlike the Monkeyface (*Quadrula metanevra*) and False Mapleleaf (*Q. fragosa*), both discussed above, *Q. quadrula* and its additional Upper Mississippi River congeners (see just below) are presently very successful members of this river's mussel community. For reasons that are doubtless physiological, though they are not understood in detail, these quadrulae tolerate impoundment (which has been the character of the UMR for the past four decades). In fact, the Mapleleaf (see Bates, 1962) exemplifies their ability to exploit impoundment conditions, notably including accretions of finely divided, unstable sediments. Its conchological phalanges, for example, may be of value in buoying (and otherwise stabilizing) the juvenile animal in soft substrate.

In spite of the Mapleleaf's positive response to impoundment, it is clear that this species once ranged far more widely in the UMR drainage than is now the case. It has recently been taken alive in the St. Croix River of Wisconsin and Minnesota, far upriver from Pool 8, the northernmost pool where it now is commonly found. Adverse water quality in the upper Pools, doubtless emanating from Minnesota's Twin Cities, is surely to blame.

The Mapleleaf now is widely distributed and frequently encountered in Pool 9 and below. Contributing to this survival is the continuing persistence in the UMR of this mussel's only recorded glochidial host, *Pylodictis olivaris*, the Flathead Catfish. There must be at least one other, unrecorded host, which perhaps occurs in the UMR. *Quadrula quadrula* is abundant

in the Auglaize River of Ohio, which is a tributary of the Maumee River, and *P. olivaris* is unknown in the entire Maumee drainage (C. F. Clark, Green Valley, Arizona, personal communication).

Quadrula nodulata, Wartyback

Unlike the preceding species (*Quadrula quadrula*, Mapleleaf), the Wartyback apparently is *natively* restricted to southern UMR Pools. There it is not only a stable member of the indigenous mussel community, but also a competent exploiter of habitats disturbed by man. Also, the known glochidial hosts of *Q. nodulata* (ictalurid and centrarchid fishes) substantially outnumber the Mapleleaf's and apparently are doing well in the UMR.

Quadrula pustulosa, Pimpleback

This is by far the most plentiful, widespread, and commonly encountered member of its genus in the UMR; indeed, only two species of mussels outstrip the Pimpleback in these respects, Threeridge, *Amblema plicata*, and Fawnfoot, *Truncilla donaciformis* (both discussed below). The success of *Quadrula pustulosa* doubtless is due in large measure to its large number and variety of glochidial hosts, as well as to its lack of narrow habitat restriction.

Tritogonia verrucosa, Buckhorn

In three seasons' investigations the Academy has found Buckhorn alive in the UMR drainage only in the St. Croix River and only in 1977. Only bones and an occasional gaper have been recovered from the Upper Mississippi proper. *Tritogonia verrucosa* has several recorded glochidial hosts, all of which are faring well in the UMR. However, this mussel faces extinction in the UMR and some of its tributary streams. Nothing can confidently be stated about the Buckhorn's UMR habitat preferences, and little that is taxon-specific can be done to favor its conservation other than to give it legal protection at the state level throughout the UMR valley. Elsewhere, *T. verrucosa* fares well enough that its national protection as a Threatened or an Endangered Species would be highly debatable. That view may become invalidated, however, because the Buckhorn's status in the UMR strongly suggests that it is unusually sensitive to declining water quality.

Cyclonaias tuberculata, Purple Pimpleback

This species is not a true member of the Cumberlandian element (van der Schalie and van der Schalie, 1950) of the Nearctic

naiad fauna, but, as a lithophile, it is ecologically allied to those species. Today its last flourishing populations occur in Tennessee River headwaters, notably the Clinch River in western Virginia and eastern Tennessee. There the streambeds are gravel riffles and bedrock shoals. Neither such habitats nor *Cyclonaias tuberculata* itself was ever very plentiful in the Upper Mississippi River, and the now nearly complete destruction of the former (by blasting and inundation) has meant the demise of the latter. What little remains of suitable habitat (e.g., the shoals at Rock Island, Illinois, and Keokuk, Iowa) might be conserved, but *C. tuberculata* surely is below recruitment level and approaches extirpation. Occasional, very old individuals still are found alive. As examples (noted earlier), in 1978 personnel of the Wisconsin Department of Natural Resources took one from a relic bed in Pool 4 at the Wabasha, Minnesota, bridge and a professional clammer caught another in Andalusia Slough, Pool 16. However, the Academy's three-year study has produced no evidence of juveniles or any other signs of successful reproduction by *C. tuberculata*. Finally, no glochidial host is known.

Fusconaia flava, Pigtoe

This is among the more common mussel species in the UMR. This is consonant with its number of glochidial hosts and its at least adequate recruitment. Also contributing to the Pigtoe's success is its apparent indifference to substrate type.

Fusconaia ebena, Ebony Shell

The Ebony Shell has several recorded glochidial hosts, but apparently only one of them (*Alosa chrysochloris* Rafinesque), the Skipjack Herring, is widely used in nature. The Skipjack is an anadromous fish, and, when the hydroelectric dam at Keokuk, Iowa, was closed in 1913, the Skipjack's upstream migration effectively ceased. Once the mussel most important to the pearl button industry, *Fusconaia ebena* quickly went into decline. Few living specimens have been reported in recent years; for example, the Academy's only such record is an animal taken by brail from a residual bed in the main channel border just above Homer, Minnesota, in 1978. There can be no question that the Ebony Shell is almost extinct in the UMR. Occasional Skipjack manage to gain Pools above Keokuk, but these few specimens are inadequate for restoration of the Ebony Shell to the Upper Mississippi. Until fishways are installed in the Keokuk Dam and others, or until this dam is removed, paucity of glochidial host(s) will continue to be a problem for the Ebony Shell.

Unfortunately, even were migration of the Skipjack re-established, it is doubtful that the Ebony Shell could re-invade the UMR, because it is not successful in Pools below Keokuk. One

infers that adverse water quality precludes this species' re-occupying the UMR at any point.

Megalonaias gigantea, Washboard

The Washboard is second only to the Threeridge (*Amblema plicata*) (below) as a commercially important mussel in the UMR. However, in spite of its numerous and varied glochidial hosts, *Megalonaias gigantea* is in decline, and cessation of its harvest is recommended. Academy investigators have found almost no evidence of this species' reproduction during eight months' intensive field work. Not surprisingly, especially in view of its increasing rarity, the Washboard has become almost exclusively a creature of the great beds; elsewhere in its geographical range it does not necessarily exhibit this apparent habitat restriction, though, as an adult, *M. gigantea* is characteristic of a given stream's deepest portions. This species continues to flourish in portions of its original range and thus is not a reasonable candidate for federal protection as an Endangered or a Threatened Species. Nevertheless, the UMR population of Washboard deserves conservation at State level, especially because it is commercially exploited.

Amblema plicata, Threeridge

Threeridge are the most (or next to the most) abundant, widespread, and regularly encountered mussels in the UMR. An unusually large number and variety of glochidial hosts are of service to this species, which has the added advantage of having no apparent habitat restrictions.

Plethobasus cyphyus, Bullhead

The Bullhead is another species that was relatively uncommon in the UMR and has become a great rarity. Recent discoveries of living specimens have been very few and mostly from the great Kilpeck bed (or its vicinity) in Pool 17. However, among these few individuals can be distinguished several age-classes, so there is a little hope that *Plethobasus cyphyus* may still be viable as a species locally in at least certain Pools (though these have not been identified as yet). Further investigation, especially in the Corps' Rock Island District, might provide information about areas whose conservation would benefit the Bullhead. Unfortunately, however, this species apparently is unusually sensitive to adverse water quality; this is the best explanation of its increasing rarity, because physically appropriate habitat abounds and its only recorded host, *Stizostedion canadense* (Smith), the Sauger, remains plentiful in the UMR. Should this inference about the cause of the Bullhead's poor

success prove to be correct, then this species, also, faces extinction in the UMR, for stabilization (and even improvement) of UMR water quality cannot reasonably be expected for some years to come.

Pleurobema rubrum, Pink Pigtoe

As discussed earlier, most records of *Pleurobema* from the UMR probably represent *P. rubrum* (usually called "*P. cordatum*"). There remains some question about the range of this species; in the UMR it is sporadically distributed. In the study area, for example, occasional living specimens have recently been found in the lower St. Croix River and in Pools 4, 5, and 9 (Fuller, 1978b; P. Thiel, WDNR, La Crosse, personal communication). No glochidial host has been unequivocally identified. Inadequate support in terms of larval host(s) and/or water quality probably is responsible for the Pink Pigtoe's decline to near-extirpation.

Pleurobema sintoxia, Round Pigtoe

As discussed earlier, *Pleurobema sintoxia*, like *P. rubrum* (above), has been reported as "*P. cordatum*". In the case of the Round Pigtoe, however, there are few historical records and no recent ones. Nothing is known of this species' habitat requirements in the UMR. For reasons unknown, *P. sintoxia* probably is already extirpated in this river.

Elliptio crassidens, Elephant Ear

Like the Ebony Shell (*Fusconaia ebena*, above), the Elephant Ear is dependent upon the Skipjack Herring, but in this case the Skipjack is the *only* recorded glochidial host. Consequently, it appears that the Elephant Ear was doomed to extinction in the UMR by the Keokuk Dam. Possibly excepting the Academy's tentatively identified 1977 material from the St. Croix River, living material has not recently been recorded from the UMR drainage.

Elliptio dilatata, Spike

This species has several glochidial hosts that are doubtless plentiful enough for the parasite's needs in the UMR, but the Spike nevertheless is in difficulties there, in spite of the obvious availability of congenial physical habitat. For three years the Academy found no evidence of recent recruitment by *Elliptio dilatata*, although the Spike is rather common in some areas. This apparently is another instance of inadequate water quality causing a species' jeopardy.

Obliquaria reflexa, Threehorn

On the strength of the Academy's 1977 field data and their relationship to Ellis' (van der Schalie and van der Schalie, 1950), the Principal Investigator (Fuller, 1978b) concluded that the proportional representation of the Threehorn, while always comparatively small in the UMR, has remained almost unchanged for at least half a century. The Academy's 1978 and 1979 results confirm this appraisal. The most noteworthy consideration is the remarkably successful recruitment by *Obliquaria reflexa* in shallow-water communities of juvenile mussels opposite Winona, Minnesota, in Pool 6. This evidence of recruitment is remarkable because apparently no glochidial host(s) of *O. reflexa* have ever been identified; indeed, this is one of only three Nearctic mussel species for which facultative glochidial parasitism has been claimed (Fuller, 1974).

Proptera alata, Pink Heelsplitter

The Pink Heelsplitter is rather an enigma. The animal occurs in most UMR Pools, but is nowhere abundant. On the other hand, this Heelsplitter shows some recruitment, and it has a list of glochidial hosts that, though brief, consists of species that currently fare well in the UMR. *Proptera alata* appears to exhibit no marked substrate preferences.

Proptera laevissima, Pink Papershell

For reasons given by Fuller (1978b), this species seems not only to tolerate, but also to exploit the impoundment conditions that were imposed on the UMR by the 9-Foot Navigation Channel Project about 40 years ago. *Proptera laevissima* successfully inhabits numerous substrate types, including some that are inimical to most mussels (e.g., moving bedload). Its recorded hosts are fishes that prosper in the UMR. Additional evidence of the Pink Papershell's prosperity are the large, recruiting populations that the Academy discovered in 1977 in the poor-quality water of Pool 4.

Proptera purpurata, Purple Pocketbook

This species is treated here because of a recent record established by Perry (1979) on the basis of a single specimen from the unimpounded portion of the UMR below Locks and Dam 27. Nothing is known of the optimal habitat(s) or glochidial host(s) of *Proptera purpurata* in the UMR.

Proptera capax, Fat Pocketbook

This is one of only two UMR mussel species that enjoy national, federal protection as Endangered Species. Of course, national injunction against the Fat Pocketbook's being molested is of little value if its local natural history, including geographical distribution, is not understood. Almost 50 years ago the Ellis survey found *Proptera capax* alive in small numbers and in several Pools, but the Principal Investigator has no knowledge of living representatives of this species taken from the UMR since then. The Fat Pocketbook probably is now extinct in the UMR. Nevertheless, remarks about this species' glochidial host(s) and preferred habitat are appropriate. Shira (1913) may have implicated the Blackstripe Topminnow, *Fundulus notatus* (Rafinesque), as a host of *P. capax*; this indication, however remote, is the closest thing to an identification of a Fat Pocketbook larval host that the literature provides. The most recent published account (Branson, 1966) of taking *P. capax* suggests that this species favors lentic habitats.

Leptodea fragilis, Fragile Papershell

This species is widespread, rather plentiful, commonly encountered, of broad habitat tolerance, and reproductively competent in the UMR, probably at least in part because its only recorded glochidial host is the successful Freshwater Drum, *Aplodinotus grunniens*.

Leptodea leptodon, Narrow Papershell

The Narrow Papershell apparently never was plentiful in the UMR. Aside from the supposition that this species natively frequents riffles, nothing is known of its natural history.

Ellipsaria lineolata, Butterfly

Like the Threehorn, *Obliquaria reflexa* (above), the Butterfly evidently has always been a comparative rarity in the UMR, but, for reasons that are not understood, has managed to recruit itself adequately, though not plentifully. Unlike the Threehorn, however, *Ellipsaria lineolata* appears to have suffered a drastic southward range reduction since the turn of the century. It was recently found alive in the St. Croix River (Fuller, 1978b), but apparently does not reappear downstream until Pool 5A of the UMR (P. Thiel, WDNR, La Crosse, personal communication). Farther downstream the Butterfly seems to be very rare through Pool 18. *E. lineolata* is recorded as a parasite of several UMR fishes, including the highly successful Sauger and Freshwater Drum, so larval host problems surely are not the cause of its geographical restriction. Similarly, deterioration of physical habitat

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does not seem to be at fault: for example, the Academy recently discovered a thriving population of Butterfly that extended from Locks and Dam 19 at Keokuk, Iowa, several miles downstream to the UMR confluence with the Des Moines River at the Missouri state line (Fuller, 1979b). If only by process of elimination, degraded water quality seems to be this species' chief problem in the upper portion of its former UMR range.

Truncilla truncata, Deertoe

This species is reminiscent of the Pink Heelsplitter, *Proptera alata* (discussed above), in that it persists as a widespread, but not plentiful species and in that its true ecological status in the Upper Mississippi River is debatable. Degraded water quality influences the geographical range(s) of many UMR mussel species; in some cases (e.g., *Ellipsaria lineolata*, discussed just above) this factor appears sharply to subdivide a species' original range into at least two, currently more or less hospitable portions. Again as in the case of *P. alata*, water quality alone does not satisfactorily explain the circumstances of the species in question, for *Truncilla truncata*, also, is a persistent species, however seemingly unsuccessful, over a wide range. The glochidial-host factor, also, does not account for the Deertoe's status in the UMR biota: *T. truncata* infects Sauger and Freshwater Drum, both of which are successful UMR fishes. Possible degradation of physical habitat, also, does not seem operative, else Deertoe would not be as widely ranging as they are. It appears that one can assume only that *T. truncata* has responded moderately and generally to decline in the quality of aquatic life in the UMR and/or that this species long since suffered a severe setback (e.g., the depredations of the pearl button industry) and is now only gradually reasserting itself in the UMR malacofauna. Confounding attempts to understand the true status of the Deertoe in the UMR is confusion of its juveniles with those of its congener the Fawnfoot (see *Truncilla donaciformis*, discussed immediately below). The facts are that young *Truncilla* dominate UMR juvenile naiades and that there is as yet no way unequivocally to distinguish between immediately post-metamorphic juveniles of *T. truncata* and *T. donaciformis* (the Academy's researches during the past three seasons have brought to light almost innumerable young *Truncilla*, but to which species they belong remains moot). On the other hand, adult Fawnfoot, *T. donaciformis*, are vastly more numerous in the UMR than are adult Deertoe, *T. truncata*. Therefore, it seems fair to conclude that the overwhelming majority of juvenile *Truncilla* in the UMR are probably *T. donaciformis*. This inference is additionally supported by the Academy's 1978 experience with the community of (principally) juvenile mussels in the post-impoundment overbank habitats in shallow-water portions of the main channel border (and adjacent backwaters) that lie opposite Winona, Minnesota, where the majority of juvenile *Truncilla* were *T. donaciformis*.

These observations notwithstanding, the fact remains that the ecological status of *Truncilla truncata* in the UMR cannot yet be unequivocally defined.

Truncilla donaciformis, Fawnfoot

The results of the Academy's three seasons of study of Upper Mississippi River naiades have combined to show that the Fawnfoot is the most successful freshwater mussel in the modern impounded UMR. In spite of any contest (or confusion) with this species' congener *Truncilla truncata* (the Deertoe, discussed immediately above), juveniles of *T. donaciformis* assuredly abound in most Pools studied; not even the plentiful Threeridge, *Amblema plicata* (see above), can realistically compete with the Fawnfoot for ranking as the most abundant UMR naiad. *T. donaciformis* has been found in a very wide range of UMR habitat types. This species' juveniles are encountered almost everywhere, including such presumably unfavorable naiad habitats as areas of moving bedload in the main navigation channel and more or less stagnant areas of the main channel borders and their vicinities. Its only recorded glochidial hosts are the Sauger and the Freshwater Drum. These fishes commonly host other successful UMR mussel species, especially those rather delicate species whose gravid females' shells are easily ruptured by the Drum, which then is easily infected by the contents of its victims' marsupia.

Obovaria olivaria, Hickorynut

Today the Hickorynut is successful in only the lower Pools of the study area. Its original UMR range is somewhat obscure, so its fate in the Mississippi River during recent decades is uncertain. On the other hand, *Obovaria olivaria* flourishes locally, so there is no overwhelming reason to interpret it as being an animal jeopardized to any given degree. This species is, then, something of an enigma and thus reminiscent of *Truncilla truncata* and *Proptera alata* (both discussed above). The recorded glochidial hosts of the Hickorynut are persistent fishes in the UMR. Substrate suitable for *O. olivaria* is prevalent in the UMR.

Therefore, it seems that such survival problems as the Hickorynut faces in the UMR may be created by adverse water quality. However, this notion is weakened by the Academy's 1978 discovery at Winona of extensive beds of juvenile mussels, including species (such as *Quadrula metanevra*) far rarer and presumably more sensitive than the Hickorynut, which was not found there. It may be simply that *O. olivaria* is an essentially southern species in the UMR.

Actinonaias carinata, Mucket

Once abundant and widespread throughout the UMR, the Mucket, a very valuable commercial species, is now in grave jeopardy. It was damaged by the pearl button industry, but the Ellis survey in 1930 and 1931, about two decades after the height of that fishery, encountered *Actinonaias carinata* rather commonly. Increasingly poor water quality since then doubtless has hurt the Mucket. Perhaps a yet to be understood peculiarity of 9-Foot Channel impoundment has contributed to this species' decline. In any case, the Mucket exhibits no recruitment today and, like most rarities, is confined to the great beds. Even in these congenial habitats it is rare; among the very few beds known to support it are those at Hudson (St. Croix River), Prairie du Chien (Pool 10), and Kilpeck (Pool 17). Especially from the viewpoint of commerce, all harvest of the Mucket should be prohibited. Multi-state cooperation would be necessary because, on account of its persistence elsewhere in its original range, *A. carinata* possibly does not yet warrant federal protection as an Endangered or even a Threatened species. State-level protection could reasonably begin with surveillance of great beds such as those mentioned above.

Actinonaias ellipsiformis, Ellipse

Characteristically a small-stream species, the Ellipse always has been rare in the UMR. Even minimal environmental adversity in a large river could have been expected to lead to its elimination, and this is precisely what appears to have occurred. The Ellis survey almost 50 years ago recovered only a few specimens of *Actinonaias ellipsiformis*, and none appears to have been positively determined in the Upper Mississippi River during the intervening years. No characteristic habitat(s) or glochidial host(s) have been identified for the Ellipse in the UMR.

Ligumia recta, Black Sandshell

Once common, even locally abundant, and widespread, this species has become extirpated or rare throughout the river. On the other hand, some host fishes and some reproducing populations of *Ligumia recta* are known, and it exhibits wide habitat tolerance.

Ligumia subrostrata, Western Pondmussel

Apparently the only published record of this species for the mainstem UMR is Coker's (1919). *Ligumia subrostrata* is characteristically found in quiet waters and in Coker's day probably occurred in such habitats as sloughs, floodplain ponds,

etc. Its recorded hosts are centrarchid fishes, which favor the same habitats. The Western Pondmussel probably occurs here and there in the modern overbank habitats created by UMR impoundment by the 9-Foot Navigation Channel Project.

Carunculina parva, Lilliput

In regard to glochidial hosts and habitat preferences, the remarks about *Ligumia subrostrata* (immediately above) apply equally well to the Lilliput. However, *Carunculina parva* is at home in the UMR proper. Academy investigators have found Lilliput abundant in many Pools, and this species' are among the more commonly encountered juveniles, even in the main channel, where immediately post-metamorphic young seem to ride moving bedload on rafts of byssal threads and vegetable debris. In spite of this device, most young *C. parva* probably die. Adults are rare, but occasional local pockets (as opposite Winona, Minnesota) are encountered. The rather widely held assumption that the Lilliput is a rarity in the UMR is no longer tenable. Centrarchid fishes are the Lilliput's hosts.

Lampsilis teres, Yellow Sandshell

In the heyday of the pearl products industry on the UMR, the Yellow Sandshell was considered the most valuable mussel, primarily because of its fine nacre, its abundance, and its tolerance of many habitats (including sandbars that developed between adjacent wingdams). It was then a very successful animal, even in somewhat lentic areas, and about two decades later (about 50 years ago) records of *Lampsilis teres* formed the most plentiful data gathered by the Ellis survey. It is possible that the impact of impoundment caused by the 9-Foot Channel induced phenomena unfavorable to *L. teres*. For example, the UMR fishes of greatest importance as the Yellow Sandshell's glochidial hosts are gars, most of which are substantially less successful now than they were only a few decades ago. Details of the gars' natural histories that are relevant to this discussion are obscure. Equally so are aspects of declining UMR water quality that, directly or indirectly, may have hastened the decline of *L. teres*. Finally, this species' most active recruitment occurs in Lake Keokuk of Pool 19, which is the eldest of UMR Pools, by a quarter-century's margin. That Pool 19 is presumably the ecologically most stable of UMR river-lakes may contribute to the Yellow Sandshell's success there. On the other hand, the Academy has discovered small, but apparently recruiting populations in Pools 8 and 10.

Lampsilis higginsi, Higgins' Eye

There is no UMR mussel that is more deserving of protection pursuant to Public Law 93-205 ("the Endangered Species Act of

1973") than is *Lampsilis higginsi*. The species has few known populations, but these few can both be protected and be the bases of recovery programs. Specifically, the great beds where Higgins' Eye is known to occur can be sharply defined, and its apparently most important glochidial hosts (Sauger and Freshwater Drum) have been identified. The beds in question include (but eventually may not be limited to) those opposite Hudson, Wisconsin (St. Croix River); the Whiskey Rock bed below Lansing, Iowa (Pool 9); Prairie Du Chien, Wisconsin (Pool 10); and the Kilpeck bed below Muscatine, Iowa (Pool 17). Because its hosts are common UMR fishes, their protection is not a key to conservation of *L. higginsi*. Improvement of water quality probably is important.

Lampsilis radiata siliquoidea, Fat Mucket

The greater part of a century ago the Fat Mucket was an important commercial species. Its great abundance then was doubtless due in part to its large number and variety of glochidial hosts and to its apparent indifference to substrate type. Today this species is almost extinct in the UMR. Principally at fault seems to be declining water quality.

Lampsilis ovata ventricosa, Pocketbook

This at least nominal subspecies doubtlessly is troubled in the UMR to some extent, as are all naiades under study here, but a redundant list of glochidial hosts and its tolerance of numerous substrates have permitted the Pocketbook to be rather successful. In the Academy's three seasons of study this subspecies has been regularly encountered in most Pools, and juveniles have been taken in many.

Plagiola triquetra, Snuffbox

The genus *Plagiola* is adapted to highly oxygenated riffle habitats, which man has largely eliminated in the Nearctic region (many members of this genus are extinct or nearly so). *P. triquetra* is the most widespread member, but never has been widely recorded from the UMR, whose white-water habitats were never plentiful and are almost gone. The Snuffbox is nearly or quite extinct in the UMR, but it probably could never have been well established there. No glochidial hosts are known.

Arcidens confragosus, Rockshell

Like most rarities, this mussel usually is found in the great beds or at least among dense assemblages. However, this does not seem to be simply a matter of the animal's being rare

and thus more common where mussels in general are more common. On the contrary, the Rockshell appears *always* to have been a rarity in the UMR naiad fauna. *Arcidens confragosus* can be characteristic of rocky habitats (hence the vernacular name), and it has a few, rather varied glochidial hosts.

Lasmigona complanata, White Heelsplitter

This species exhibits uneven recruitment, usually in the form of occasional juveniles found in slack-water nurseries. It is increasingly rare in the UMR, being principally confined to the great beds. On the other hand, its recorded glochidial hosts are still common, and *Lasmigona complanata* remains widespread.

Lasmigona costata, Fluted Shell

This is essentially a smaller-stream species that is probably extinct in the UMR, although at one time it had developed some local, thriving populations. It appears that these were devastated by the mussel fishery on behalf of the pearl button industry around the turn of the century. Consistent with this statement is the fact that, several decades later (and about 50 years ago), the Ellis survey (of 1930 and 1931) recorded few Fluted Shell. The one recorded glochidial host of *Lasmigona costata* is *Cyprinus carpio*, the Carp, which currently is a very successful UMR fish, but this symbiosis obviously has been insufficient to maintain UMR populations of the mussel in question.

Lasmigona compressa, Creek Heelsplitter

Lasmigona compressa is among the few Nearctic naiades that are known to have invaded (or re-invaded) the Interior Basin of Canada postglacially (Clarke, 1973). This is a mark of unusual success, but, in spite of Kakonge's (1972) work, no records of the Creek Heelsplitter's glochidial hosts seem to have been published. Also remarkable is that this animal, although a characteristically small-stream species, failed to duplicate its congeners' progress, however faulty, in the UMR (see discussions of *L. complanata* and *L. costata*, above); there are almost no records of *L. compressa* in the UMR.

Alasmidonta marginata, Elktoe

Several records of the Elktoe's glochidial hosts have been published, and all of them presumably are based on UMR data. On the other hand, *Alasmidonta marginata*, natively a small-stream species, never has been very successful in the UMR, even though it was regularly encountered in the days of the pearl button industry. Also, no contemporary notes of this species' habitat preferences are available.

Alasmidonta viridis, Slippershell

This species has very rarely been recorded from the UMR, and there are no relevant published notes on habitat or glochidial hosts.

Simpsoniconcha ambigua, Salamander Mussel

The pivotal feature of this species' life cycle is its dependence solely upon an unusual glochidial host, *Necturus m. maculosus* Rafinesque, the Mudpuppy. This large and exclusively aquatic salamander lives beneath rocks when not foraging, and this determines the Salamander Mussel's habitat. Scores of these clams have been found beneath a single rock. Unfortunately, the increasing deepening of the UMR by modifications during the last 100 years has made searching for these animals very difficult. Pollywogging is entirely ineffective, except possibly during exceptionally low-water periods, and today, in the era of the 9-Foot Channel, diving would have to be employed in any search specifically for *Simpsoniconcha ambigua*. Also in favor of diving is the ineffectiveness of conventional deep-water sampling techniques (such as brailing and dredging) in search of an animal that dwells almost exclusively *beneath* rocks. It is additionally unfortunate that, in order to facilitate navigation, most rocky habitat in the UMR has been destroyed by blasting, dredging, etc. This development doubtlessly has had a negative effect on both *S. ambigua* and its host. Added problems, in feeding and respiration, probably have been created for the Mudpuppy by the increased turbidity and suspended solids that have accompanied impoundment. Efforts to protect the Salamander Mussel in the UMR should be concentrated on conservation of the Mudpuppy and of the remaining rocky areas, and a taxon-specific search for *S. ambigua* should be undertaken in order to gather modern data on its distribution and abundance in the UMR.

Anodontoides ferussacianus, Cylinder

An unusually large quantity of recent information concerning this small-stream species' glochidial hosts is available, but it ironically is of little relevance to the UMR, where the Cylinder is ecologically extralimital except in headwater streams and the mainstem above Upper St. Anthony's Falls Pool.

Anodonta suborbiculata, Flat Floater

Formerly an inhabitant of flood plain ponds and sloughs, this Floater now is occasionally encountered in 9-Foot Channel overbank areas. It customarily lives deeply buried in viscous mud beneath several feet of water. Because of this rather deep-water habitat, it is not easily collected by hand. Consequently,

Anodonta suborbiculata probably is more plentiful along the UMR than has been realized. There is little knowledge of the Flat Floater's hosts.

Anodonta imbecillis, Paper Floater

The Paper Floater is widespread in the UMR, but naturally rare because, as a creature of ponds and small streams, it ordinarily fares poorly in the big-river environment. The rather extensive information available on the glochidial hosts and other habitat requirements of *Anodonta imbecillis* is not relevant in the present context.

Anodonta grandis, Giant Floater

The Giant Floater exhibits broad habitat tolerance in the UMR, including the main channel, on occasion. It has a long list of glochidial hosts, including many that are successful in the River, and evidence of its recruitment is regularly encountered in numerous pools.

Strophitus undulatus, Strange Floater

This is among the few Nearctic mussel species that have been claimed to exhibit facultative glochidial parasitism. Nevertheless, host fishes have been identified, and at least two are fairly prevalent in the UMR. Whether either is of much service to *Strophitus undulatus* is moot, largely because this species is a characteristically small-stream animal and rare in large rivers, including the UMR. On the other hand, it is widespread there and is one of the few mussels that survives in Pool 2, which is almost devoid of mussels. However, the Strange Floater is nowhere very common in the UMR.

The foregoing remarks are summarized simply. Substrate type rarely is a taxon-specific habitat requirement, but stability of substrate is almost always necessary. Several species in one group, the Anodontinae (Exhibit 1a), favor soft streambed, but do not require it. Hydrological factors (e.g., water depth and current velocity) seem largely irrelevant except that, for all species, they must provide protection from thermal stress and boat traffic and must be sufficient for gas-exchange and as a vehicle of nourishment. Host fish exploitation patterns apparently serve as the chief partitions among UMR naiad ecological "niches"; successful and unsuccessful species often share the same hosts, however. Favorable water chemistry seems to be the one universal habitat requirement.

The 50 species-group mussel taxa in the UMR fauna can be divided into four groups on the basis of their survivorship (Fuller, 1980b). Two of the 50 (or 4%) are federally listed, nationally protected Endangered Species: *Proptera capax* (Fat Pocketbook) and *Lampsilis higginsi* (Higgins' Eye). Fully 21 (or 42%) of the taxa are jeopardized. In the Upper Mississippi River some of these are more rare than Higgins' Eye, but, because they are reasonably healthy elsewhere, have not merited federal listing (several are on state lists of protected species, however). These jeopardized taxa are mussels that have exhibited little or no evidence of successful reproduction during recent years and probably face extirpation in the UMR. Twelve more taxa (24%) are considered troubled. They reproduce to a possibly adequate degree, but their small populations are cause for concern. The remaining 15 species are healthy. Their historical ranges have been curtailed (especially in the Twin Cities Zone), but they are physiologically tolerant of water quality elsewhere in the UMR and reproduce at or above recruitment level where the riverbed is adequately stable.

It thus appears that about 70% of the UMR mussel taxa are in some degree of difficulty. A substantial proportion of these taxa is extralimital. The loss of such animals is not as serious as the loss of fully developed members of the fauna, but it certainly is undesirable. The prospects of those extralimitals that can be saved would be improved by any program designed to aid the rest of the fauna. The recently formed Upper Mississippi River Bivalve Recovery Team (which includes Corps representation) will design at least one such program, on behalf of the Endangered *Lampsilis higginsi*. The Principal Investigator suspects that this program will include a sanctuary approach to protection of the better developed known populations of Higgins' Eye and/or research into this species' hosts above and beyond what was recorded by Fuller (1974), perhaps initially modeled along lines employed by Stein (1968), Yokley (1972) and/or Ahlstedt et al. (1980). (The techniques of massive glochidial infection that were used by Coker et al. (1921) are partially inappropriate to studies of one (or only a few) species of mussels, especially if Endangered animals are involved.) Mussel sanctuaries would benefit the entire fauna. Inquiries into glochidial hosts in the near future should not emphasize extralimital species. However, such inquiries would be of great value to any mussel studied, especially because, as noted above, glochidial hosts appear to be the most important (and perhaps the only) ecological partitions between and among species-group mussel taxa.

The 1978 revisions of Public Law 93-205 ("The Endangered Species Act of 1973") have made federal listing of an Endangered or Threatened Species a more time-consuming process. In comparison to former procedures, a much stronger case must be made for each action. This ultimately may be to the given

species' advantage, but the delay itself is not. Here is an opportunity for listing at state level to have special value.

Actinonaias ellipsiformis, the Ellipse, is a case in point. At one time this species was common in Michigan (van der Schalie and van der Schalie, 1963), but it has become rare enough to be placed on the state's Threatened list (MDNR, 1976). In neighboring Wisconsin the Ellipse has been and is rare (Baker, 1928; Mathiak, 1980). Should Wisconsin follow Michigan's lead, *A. ellipsiformis* would be legally protected in Wisconsin waters, including the eastern shallows of Pool 4, site of the only unequivocal records of the Ellipse in the entire river (Grier and Mueller, 1922-1923; van der Schalie and van der Schalie, 1950). State government is in a position to protect mussels in ways that federal government either cannot do or cannot do rapidly.

Impact of the 9-Foot Navigation Channel Project on the Upper Mississippi River Mussel Fauna

To estimate the impact(s) of the 9-Foot Navigation Channel Project on the Upper Mississippi River mussel fauna, this discussion first characterizes the changes observed in the fauna from the pre-Project period to the 1977-1979 period of the present study. Then potential agents of change, including the Project, are described and evaluated.

Changes in the UMR Mussel Fauna Concurrent with the Project

The 9-Foot Navigation Channel Project began in the late Thirties with the completion of the last of the series of locks and dams that now impound the UMR from the Twin Cities to Missouri. Impoundment itself and other factors have altered the UMR mussel fauna during the intervening four decades. Differences between the pre-Project and modern faunas can be ascertained by comparing the results of the Ellis survey in 1930 and 1931 (see van der Schalie and van der Schalie, 1950) to those of the Academy's survey in 1977 through 1979 (see Fuller, 1978b, and Appendix C of this report). Comparison of the two surveys is warranted by their similarities in study area, methodology, and level of field effort. Conclusions drawn from this comparison are essentially corroborated by other studies, especially Starrett's (1971) work on the mussels of the Illinois River, a badly polluted stream and a major UMR tributary.

The most important conclusion about the UMR naiad fauna during the past four decades is that substantial degradation has occurred. From 50 species-group taxa known to live in the River prior to the Ellis survey the modern total has declined to 32. This loss of 36% of the original number of taxa becomes somewhat less dramatic when one realizes that many of these taxa were essentially small-stream elements whose loss from the UMR does not by itself constitute a major faunal degradation. Nevertheless, loss of the small-stream taxa is only one example of the reductions in population sizes that have occurred; many other species have become so rare that they cannot reproduce sufficiently to escape extirpation. The original geographic ranges of probably all but one of the surviving taxa are now reduced, sharply in most cases. Not only the numbers of species and individuals, but also the variety of mussel life has suffered; among the taxa that have rarely been found alive recently in the UMR are the River's only recorded representatives of several genera and of the entire tribe Lampsilinae: Elliptionini (Exhibits 1a, 2).

On the other hand, about a dozen of the survivors appear to be in good to excellent health. The most dramatic instances are *Amblema plicata*, Threeridge, and *Truncilla donaciformis*, Fawnfoot, which now overwhelmingly dominate the UMR mussel fauna. Other examples, notably including most *Quadrula*, are considered in the preceding discussions of species-group taxa and habitat requirements (also, see Exhibit 98). A few taxa may even be expanding their ranges in the UMR: *Anodonta suborbiculata*, Flat Floater, is the best example. Mussels remain plentiful in a few reaches within the St. Paul District. The outlook for an ongoing UMR mussel resource is guardedly optimistic.

Agents Other Than 9-Foot Navigation Channel Project Affecting UMR Mussels

Commercial Mussel Fishery

The impact upon the UMR freshwater mussels by the commercial fishery on behalf of the pearl-products industries has perhaps never been fully appreciated. Thousands of tons of these animals were removed from the riverbed for commercial purposes during the height of the industry (from about 1890 until World War I). Some of them, including species without commercial value, apparently never have returned to the point of recruitment. Other environmental pressures combined thereafter to virtually guarantee that certain of these mussel species could not again become viable components of the UMR naiad fauna.*

The effects of the commercial fishery's extensive harvest cannot be briefly conveyed. In order to gain a sense of the gravity of the situation, the reader is referred to Coker (1919), Carlander (1954), and Fuller (1978b). It is the Principal Investigator's belief that depredation by the pearl button industry remains the single greatest blow that has been dealt UMR mussels to date.

The commercial mussel fishery persisted for at least a decade after the First World War. During the ensuing 30 years there was little commercial fishing, but about 1960 the fishery was rejuvenated in response to a new demand. Spheres cut from the mother-of-pearl nacre (i.e., innermost layer) of North American mussel shells were required as "starters" in the Japanese cultured pearl industry. During the last two decades the

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* The main adverse environmental pressures and the mussel species affected are discussed by Fuller (1980b), in the preceding sections on Taxa and Habitat Requirements, and later in this section.

modern mussel fishery, now usually conducted very proficiently by divers, has actually eliminated at least one bed and has damaged many others. In the St. Paul District the fishery is confined chiefly to Pools 9 and 10 because that is where the remaining great beds are located.

Channel Modification Prior to the 9-Foot Project

Although the 9-Foot Project was the first actually to impound the UMR, there had been several stages of prior channel modification.

The colonial period of UMR modification began about 1800, when European man gained control of the river. Shortly thereafter (in 1824) the federal government authorized a program of elimination of snags, bars, shoals, and rocky impediments and of closing backwaters. This program facilitated UMR navigation by removing impediments and diverting more (and thus faster-moving) water to the main channel. A few years thereafter, Lieutenant Robert E. Lee surveyed the UMR, but it was not until 1878 that the Government authorized the 4.5-Foot Channel.

The 4.5-Foot Navigation Channel Project involved dams at the UMR headwaters for the purpose of flood control and flow augmentation. Closing dams and longitudinal dikes diverted water to the navigation channel and increased its current speed while revetments reduced bank erosion in areas where redirected, destructive currents were anticipated. Sandbars and rocks that impeded navigation were dredged.

In 1907 the 6-Foot Navigation Channel Project was authorized. Its objectives were not different from its predecessor's, but an innovation (the wing dam) was introduced with this Project. A wing dam is an essentially rocky structure extending nearly perpendicular from shore in order to divert water toward the main channel. Riprap commonly was applied to banks opposite wing dams in order to reduce erosion caused by the currents diverted by the dams.

The purpose of the wing dam was to constrict stream flow in order to increase depth. Wing dams forced larger quantities of faster water into the navigation channel at the expense of smaller quantities that moved more slowly through the channel borders in multiple current patterns. Navigation conditions were improved, but inshore relocation of sediment was increased. Adverse impact upon the benthos, certainly upon mussels, resulted. Some mussel beds were swept away; others were buried. Yet, changing conditions on the UMR have provided an ecologically beneficial role for wing dams, as described in a following section.

The Keokuk Dam

A private-sector interest closed a trans-UMR hydroelectric dam in 1913 at the rapids at Keokuk, Iowa, thus creating Lake Keokuk, now Pool 19 of the 9-Foot Navigation Channel Project. Antedating most of the other 28 Pools by fully a quarter-century, this is the oldest Pool on the Upper Mississippi. Due to its unusually great depth, very little channel-maintenance dredging has been conducted there (USACE, 1974a). Lake Keokuk's depth protects much of its benthos not only from dredging, but also from disturbance by water traffic (Fuller, 1978b); as a result, its naiad fauna is perhaps the richest remaining in the UMR (see the modern records in Fuller, 1978b). Ironically, while the earliest Pool has the apparently best mussel fauna in the UMR, its creation involved the only certain example of a species' being eliminated from the UMR by a single identifiable factor. Because, like its fellow 28 installations, Locks and Dam 19 has never been equipped with fishways, anadromous fishes could not effectively reach the UMR above Keokuk after 1913. One of these is *Alosa chrysochloris*, Skipjack Herring, apparently the principal host in nature of the glochidia of *Fusconaia ebena*, Ebony Shell (Surber, 1913; see Fuller, 1974, 1978b) and the only recorded host for the Elephant Ear, *Elliptio crassidens* (Howard, 1914). Both of these mussels near extinction in the UMR even though *A. chrysochloris* can (or could) be found sparingly above Pool 19 long after inception of the 9-Foot Channel (Smith et al., 1971). Presumably, completion of the original structure that is now known as Locks and Dam 19 was principally responsible for the effective loss of these two species from the UMR naiad fauna above Pool 20.

Declining Water Quality

World War I stimulated population growth and industrialization in the UMR valley, notably the Twin Cities, and thus contributed to declining water quality. The Second World War induced further development, especially in and about the Twin Cities. Wartime and post-war industrialization and urbanization increased factory wastes and sewage. Ellis (1931a) described the adverse effects on water quality of such wastes a decade or so after "the Great War"; aquatic damages as a result of World War II are only now beginning to be revealed as such.

Wartime technology probably was an important stimulus in the development of insecticides. The success of these insecticides led to development of other biocides: herbicides, fungicides, and "pesticides" in general. Biocides are used primarily in agriculture, and the UMR watershed is primarily agricultural. The combination of organic wastes and biocides probably is the primary cause of eradication of mussels in the Minnesota River, for example (see Fuller, 1978b). It is not likely that organic wastes alone could have done all the damage, because some mollusks respond well to eutrophication (e.g., Dillon, 1977).

Therefore, it is probable that biocides have been, are, and/or will be an important determinant of freshwater mussel life in the UMR.

The *Corbicula* Problem

The present study documented the presence of *Corbicula fluminea* (Müller), the Asiatic clam, in the study area. This exotic mussel species can be injurious to indigenous North American naiades by tunneling beneath mussels, thus uprooting them from the streambed. As already discussed (see Methodology), a dislodged mussel commonly dies. Fortunately, the habitat preferences of *Corbicula* and Unionidae in the UMR are dissimilar.

The optimal type of substrate for mussels studied by Kaskie (1971) was viscous mud because the necessary admixture of water, sand, and finer particles is a very stable composite. This is just the streambed type that supports the best mussel bed development encountered during the present study, i.e., the communities at Prairie du Chien, Wisconsin, and at certain of the "Green Bay Sites" in Pool 19 of the Rock Island District (see Sites, above, and Fuller, 1978b). Insofar as UMR mussels, at least, are concerned, there seems to be strong correlation between relevant experimental results and observations in nature.

In contrast to most native UMR mussels, *Corbicula* is an arenophile, i.e., it prefers a sandy substrate. Accordingly, the Academy's only record of living Asiatic Clam in the study area is from loose sandbars in the St. Croix River opposite Hudson, Wisconsin. This habitat predilection may save UMR mussels from direct competition with *Corbicula*. Moreover, the Asiatic Clam apparently has not prospered in the UMR. In addition to the St. Croix population, the Academy's only records are from scattered Pools.

Impact of 9-Foot Navigation Channel Project on UMR Mussels

Within this subject area, it is useful to distinguish between two classes of impacts. One class results from impoundment itself. These impacts would occur by virtue of the locks and dams themselves, even if there were no navigation channel. The other class of impacts results from the navigation channel itself, traffic along it, and efforts to maintain it.

Impacts on UMR Mussels Caused by Impoundment

Impoundment of the UMR began with the Keokuk Dam in 1913. Modification of the trans-UMR installation in the Twin Cities

(which produced Locks and Dam 1) and creation of Locks and Dam 2 at Hastings, Minnesota, were accomplished in 1930. During the next decade most of the UMR locks and dam installations of the 9-Foot Channel Project were completed. The most recent is the Upper St. Anthony Falls Locks and Dam in the Twin Cities, completed in 1963.

To distinguish effects of impoundment from such other factors as natural flooding and pre-impoundment constriction, reference has been made to studies of other impounded rivers to identify features common to the impoundment process itself. The world's impoundment literature seems to be very sparse. Moreover, most of this literature is merely descriptive, as is commonly the case with new disciplines (impoundment biology is only a few decades old). Papers that assert physicochemical causes for biological phenomena are rare. In addition, most relevant reports are weakened by the fact that no baseline (pre-impoundment) studies had been conducted. Finally, impoundment literature deals primarily with high-dam, multiple-purpose, deep-water artificial lakes that were created to promote navigation, recreation, flood control, reservoir, hydroelectric power, and/or irrigation (see, e.g., Elliott, 1973).

Conversion of the UMR into a series of low-dam, shallow-water river-lakes was done for a single major purpose: navigation. (Some of the locks and dam installations, mostly pre-dating the 9-Foot Channel, have hydroelectric capability.) Other recreational advantages (e.g., water skiing, sailing, fishing, gunning waterfowl) have developed over the last 40 years or so, but commercial navigation has always been the main concern of the 9-Foot Channel Navigation Project.

It is clear that UMR impoundment differs substantially from deep-water types found throughout the world in terms of ecological factors, as well as in terms of purpose and usage. At maturity most deep-water impoundments exhibit features that do not afflict the UMR, such as hypolimnetic oxygen elimination; thermal, chemical, and sedimentary stratification; and enormous hydrostatic pressure. However, in the early stages of development deep-water impoundments do not differ materially from shallow-water ones. This is shown by the many observations common to reports in Ackermann et al. (1973) and to a series of papers about the rather shallow Cow Green Reservoir on England's River Teas. Comparison of these two sources is especially persuasive because each includes post- *and* pre-impoundment surveys. Consequently, the investigator can draw upon the world literature of the early developmental stages of deep-water impoundments as an aid in reconstructing the early history of environmental disruption caused by the 9-Foot Navigation Channel Project.

Throughout the world, damming a fluviatile waterway has induced an immediate, brief, three-stage biological process in the immediately upstream waters.

First, as the water rises, there is massive death of slow-moving and immobile organisms. Newly flooded grounds release nutrients, which are augmented by those from dead organisms. Second, within a few years an explosive increase of species more tolerant of the new lentic conditions begins. The third and final stage exhibits reduction in variety, population sizes, and biomass of the fauna.

These three stages of biotic maturation in an impoundment appear to be a universal pattern observed in such widely separated areas as tropical Africa and South America (Petr, 1978), England (Armitage, 1977b), Poland (Krzyžanek, 1970), Canada (Nursall, 1952), and Japan (Morishita, 1973). Substrate and food appear to be two principal factors contributing to changes in the benthos of the newly impounded area (Armitage, 1977b; Petr, 1978).

Shift from Rheophilic to Limnophilic Species:

The greatly increased settling of suspended matter from the newly slowed river water occurs throughout the impoundment, but especially in the overbank areas, where current is least. The immediate biotic effect of slower current and increased sedimentation in the old channel is reduction and even extirpation of rheophilic species. This tends to reduce the number of mussel species since there are fewer limnophilic than rheophilic mussels.

Loss of Rooted Macrophytes:

Sedimentation may have other, more subtle effects. For example, fine-grained materials precipitating in the shallows create a decreasingly firm substrate, from which rooted macrophytes soon lose foothold and disappear. This process is aggravated by erosion caused by re-oriented currents, a result of the river's being slowed by the dam. Macrophyte rootstock stabilizes substrate and provides attachment sites for the byssal threads of juvenile mussels. Loss of rooted macrophytes thus contributes to making a habitat less suitable for mussels.

Food Chain Changes:

Death and decay of rooted aquatic plants contribute to the pulse of nutrients in stage two, which stimulates macroinvertebrates and those fishes that prey upon them. Ironically, loss of rooted macrophytes may also reduce vital habitat for macroinvertebrates and substrate for the eggs of certain fishes.

This loss means that most oxygen evolution in impoundments is performed by phytoplankton. This flora gradually assumes a

greater role in the food web and supports an increasingly important fauna of microcrustaceans (especially as the role of macroinvertebrates is curtailed in the shallows and old channel, as noted above). The most important food chain in many impoundments thus becomes plankton-to-fish (Isom, 1971).

The impounded ichthyofauna (fish community) eventually is dominated by limnophiles, planktivores, species whose eggs are pelagic, and slow-swimming species (fast swimmers are at a disadvantage in poorly aerated waters because dissolved oxygen is insufficient to support evolution of the high metabolic energies that they require).

In many deep-water impoundments the net biotic impact of these changes has included almost complete loss of macrobenthos and substantial alteration of the ichthyofauna (see Ackermann et al., 1973). However, the shallow UMR river-lakes have fared very well in comparison. For example, freshwater mussels remain a major component of UMR macrobenthos, even though they have experienced reductions since inception of the 9-Foot Channel. The ichthyofauna, also, has been reduced, but no major taxonomic portions have been eliminated (Smith et al., 1971). The latter point benefits mussels because of the almost universal dependence of their parasitic larvae upon fishes (see Fuller, 1974).

Low Dissolved Oxygen (DO):

The crucial difference between high- and low-dam impoundments obviously is water depth; equally obviously, there must be a range of depths at which such factors as pressure, oxygen depletion, prolonged cold, and stratification begin to damage the biota severely. The UMR has at worst only approached such a range. However, with respect to at least one of these factors (oxygen), there is an inauspicious report in the literature.

In a limnological history of Volta Lake (a deep-water impoundment in Ghana, West Africa) since its earliest days, Obeng (1973) stated that (1) during this lake's first four weeks of life oxygen in surface waters fell to 15% of saturation and that (2) at the end of this period there was in some parts of the lake no dissolved oxygen at depths of only 10 meters (about 33 feet). The first observation is disquieting because oxygen decline in subsurface waters probably was greater than at the surface, where photosynthetic replenishment of DO ordinarily is maximal; DO values less than 15% of saturation probably impact benthos adversely. The second observation is disturbing because there are some areas of the UMR that support abundant mussels at depths approaching those at which Obeng found zero DO. In Pool 13, for example, thriving mussel communities exist (in the main channel) at depths of from about 20 to about 25 feet. It is possible that DO concentrations at

these depths, while probably somewhat higher than at 33 feet, could still be low enough to have adverse effects on mussels. The unsettling note in these remarks should be tempered by realization that a UMR river-lake is not strictly comparable to a deep-water impoundment elsewhere.

Increased Shallow-Water Areas:

Impoundment of the UMR probably increased shallow-water areas. This could have had beneficial effects on mussels by, for instance, increasing availability of suitable nursery habitat. However, it also greatly magnified the adverse effect of three natural processes: water level fluctuations, wave action, and abrasion by ice.

Each of these is a phenomenon characteristic of natural water bodies, at least large ones in temperate regions, such as the UMR. However, impoundment of the UMR has aggravated each by increasing the extent of the River's shallow-water areas. According to the Academy's observations over three seasons in the field and in most UMR Pools, there is almost no mussel fauna in the littoral area of the main channel, at least partly because of these three factors in combination.

Unnatural fluctuations (drawdowns) in water level were increased in frequency and extent once installation of the locks and dams provided man a vastly increased opportunity to interfere with natural river flow (fortunately, severe drawdowns no longer are permitted).

Wave action has increased because of the great breadth of many UMR Pools and the much higher volume of large-vessel commercial traffic. The Academy team has experienced up to four-foot summer waves on certain Pools (notably, lowermost Pool 5). Increased wave action affects mussels adversely by tending to dislodge rooted aquatics and increase suspended solids.

Abrasion of the littoral by ice for much of the year occurred in the upper UMR before any of man's manipulations, but the 9-Foot Channel Project's creation of widespread overbank habitats has subsequently increased the area subject to this action.

Impacts on UMR Mussels Caused by the 9-Foot Navigation Channel and Associated Activities

The major adverse environmental impacts on mussels that are caused by specifically navigation-channel-related activities are associated with channel maintenance (dredging, bank repair,

etc.) and especially the disposal of dredged material. Other relevant factors include navigation channel traffic, locks and dams maintenance and operation, and construction projects.

Channel-Maintenance Dredging:

This is by far the ecologically most significant activity required by the 9-Foot Channel Project. The next section of this report considers the various procedures and alternatives in the context of recommendations for enhancement of the mussel resource by O & M activities (see, also, Fuller, 1978b). The adverse impacts of the four aspects of current channel-maintenance dredging practices are discussed here.

1. Removal of Material from the Riverbed

The St. Paul District operates two dredging plants, the Dredge WILLIAM A. THOMPSON and the Derrickbarge HAUSER. The THOMPSON is a hydraulic dredge armed with a cutterhead for penetration of the riverbed. The HAUSER uses a clamshell bucket. Either plant and instrument can destroy mussels on contact. Channel-maintenance dredging is conducted in areas of shoaling bedload, which, as an unstable substrate, is generally inhospitable to mussels. Consequently, neither plant damages many mussels by direct contact with the dredging machinery itself.

2. Sediment Migration

Adjacent to the cutterhead or clamshell dredge, the riverbed is disturbed during dredging, and sediments are resuspended into the water column. They migrate and resettle downstream, where they may bury benthos, including mussels. In order to evaluate this possibility, the Academy surveyed at least one quarter-mile of riverbed below each dredge cut that was examined. No evidence of mussel beds in that reach was ever found. In adjacent channel borders the Academy found no evidence that mussels had been damaged by previous sediment migration.

In response to concern that precipitation of sediment disturbed by dredging may lead to burial and perhaps death of mussels, the St. Paul District supported a bioassay of the impact of sedimentation upon mussels. This study was conducted at the Fish and Wildlife Service National Fishery Research (then "Fish Control") Laboratory at La Crosse, Wisconsin, at the same time that the Academy's 1977 field crew was investigating conditions in the field.

The only precursor of the National Fishery Research Laboratory bioassay is a study by Ellis (1936), who reported great mortality of mussels buried beneath only a few millimeters of silt. Ellis' report led later students to regard sedimentation as an expecially significant enemy of mussel life. For

example, the Principal Investigator (Fuller, 1974) employed Ellis' results in what he now suspects may have been an unnecessarily pessimistic essay on the subject of mussels and sedimentation. In any case, the Service's report (Marking and Bills, 1977) showed that at least some species of mussels are far more tolerant of even deep burial than had previously been thought.

While the study by Marking and Bills was underway, the Academy's field crew was gathering observations on mussel beds in the vicinity of high-frequency historical dredge cuts. The most significant instance was the discovery of living *Lampsilis higginsi* in the midst of a thriving mussel community located opposite Hudson, Wisconsin, in the St. Croix River only a few meters from a cut that has been frequently dredged throughout the history of the 9-Foot Navigation Channel Project. The Service's and the Academy's results, then, both indicate that there is little likelihood that sediments migrating from Corps channel-maintenance dredging sites have major adverse impact upon mussels at present.

3. Transport of Dredged Material

Material dredged by the THOMPSON proceeds directly onto land through pipe. The HAUSER dredges material onto barges, which then move inshore. There the material is either redredged onto land (the current practice in the St. Paul District) or dumped into the shallows and then redredged onto land. In either case, moving a living mussel onto land causes its death by desiccation.

When the HAUSER and its fleet practiced two-stop transport, there was an additional threat to mussels. Animals buried by shallow-water dumping probably did not survive. It is likely that they either remained buried or were dredged onto land.

4. Disposal of Dredged Material

As already noted, mussels conveyed onto land will die. If disposal of material is aquatic, however, mussels contained in it have a small chance of burrowing far enough out of it to come into contact with the water column; most will remain buried, asphyxiate and/or starve, and die. Aquatic disposal can be open-water or in backwaters. In either instance, as in terrestrial disposal, there is the danger of the material's eroding back into the water and burying nearby mussels. Backwater disposal (which can have beneficial aspects, as discussed in the next section of this report) can have the disadvantage of burying unusually dense assemblages of mussels in nursery beds.

Navigation Channel Traffic:

Channel traffic consists of both commercial and recreational craft. They can have several types of impact potentially

injurious to mussels, including grounding, petrochemical leaking and spillage, and waves. All can damage littoral benthos locally, and petrochemical impact often is far more widespread. Because of its volume, commercial traffic probably has the greater effect, except possibly in the case of waves, often aggravated by the irresponsible handling of private craft.

Locks and Dams Maintenance:

Preservation of surfaces involves sandblasting and painting; the results can include both increases in suspended solids and additions of toxic materials from spillage, respectively. The latter point pertains to lubrication, also, as of gear systems, and some additional petrochemical leakage and spillage doubtless is caused by the use of Corps boats in the vicinity of locks and dams. Except in places of intense activity by the Corps (such as the Fountain City Service Base in Pool 5A) the adverse impacts of any solids and toxic substances added to the water during maintenance and repair of locks and dams surely are minute in comparison to roiling, leakage, and spills created by private-sector vehicles (towboats, barges, and pleasure craft). Somewhat at variance to this conclusion, of course, would be the effects upon benthos when and if herbicides are used in weed control near these installations. Unfortunately, there appear to be no comprehensive studies of the effects of biocides (including herbicides) upon freshwater mussels.

Scour (chiefly by ice in winter) can score and undermine lock walls. Fill (riprap, grout, etc.) is introduced in order to replace the eroded materials. Increases in suspended solids, once again, plus burial of organisms, can result. However, these repairs are infrequent, localized, and short-lived, and benthos in the vicinity of locks and dams ordinarily is extremely impoverished, so grouting and riprapping probably have minute biological impact.

Heaters sometimes are employed in winter to keep dam gates free of ice. The resulting open-water areas are somewhat warmer than adjacent waters. This probably has some influence upon such fish as congregate in the nutrient-rich waters immediately below dams. Directly or indirectly, there may be further influence on the glochidia of bradytictic mussel species (i.e., those whose larvae overwinter as parasites on fishes). Neither the nature nor even the existence of such an impact has been established, however.

It is apparent that there are several aspects of repair and maintenance of locks and dams that logically could damage local biota, but the presumed impacts have been studied poorly, and are understood only by inference, if at all. Far more important are the facts that these phenomena are negligible in comparison to certain other UMR ecological problems (as noted

above) and that mussels, for example, are rare in the vicinity of locks and dams.

The Principal Investigator has readily concluded that any adverse impact created by operation, maintenance, and repair of locks and dams is of minute significance in the biology of UMR mussels. Consequently, there is no point in the Corps' expending large resources on this problem in the foreseeable future.

Locks and Dams Operation:

The operation of movable parts of these installations probably has no adverse impact upon mussels. Ironically, opening locks doubtless has a small favorable effect by facilitating the up- and down-river movements of fish.

Construction:

It is not possible now to determine the environmental impact of the actual original construction of the locks and dams, largely because there are no pre-project baseline studies that are appropriate to this specific determination. Modern construction by the Corps in association with the 9-Foot Channel consists of a few activities, which are minor in comparison to the enormous effort that was involved in creating the locks and dams. The impacts of these activities can be somewhat evaluated, especially in regard to mussels, chiefly because the Academy surveyed a number of potential construction areas during the present study. These are areas where the Corps has contemplated bank repair, reconstruction of parts of locks and dams, or installation of culverts through earthen dams in order to improve backwater flow.

Construction and reconstruction consistently is not a problem in the vicinity of locks and dams, where mussels are very rare. Mussels doubtless can be harmed during culvert installation, but they are apt to be rare in such areas, which exhibit poor flow and aeration (otherwise, a culvert would not be required); the presence of a rare or Endangered species in such an inhospitable place is even more unlikely. The benefits of such a culvert to the ecosystem surely outweigh the possible, but minor damage to mussels at the time of its construction.

Bank repair ordinarily consists of applying riprap to eroding, slumping shores. By stabilizing a source of erosion, plus the adjacent riverbed, bank repair is another ecosystematic benefit. It commonly occurs where shoreline promontories are being gradually eroded (as at the heads of islands). The upstream margins of these promontories are favorable habitats for mussels, so it is prudent to conduct benthic surveillance there prior to initiation of bank repair in order to avoid unwitting burial of mussel beds by deposition of material.

Stabilization of Water Level:

The preceding impacts have been largely adverse; there are, however, some aspects of the 9-Foot Navigation Channel Project that are beneficial to mussels. Maintaining a predictable river flow (and thus depth) in the interest of commercial navigation has always been the main objective of the 9-Foot Channel Project. Stabilization of water level (and thus of aquatic habitat) became a very positive consequence of maintaining the channel. Widely fluctuating water levels were a normal feature of the pre-impoundment UMR and did not prevent the existence of a healthy mussel fauna. However, such fluctuations have primarily negative effects on mussels. At times of low water, desiccation of characteristically shallow-water species and/or of species that use the shallows for nursery areas occurs; during high water suspended solids increase dramatically.

Floods, of course, still occur on the UMR. However, the 9-Foot Channel Project was not initiated in order to control floods; in fact, a locks and dam installation releases the constrictions of its roller, tainter, and dam gates in times of flood. Nevertheless, in comparison to the circle of the seasons, a flood is short-lived, and not nearly as harmful to mussels as was the desiccation of shallow-water areas that regularly recurred before the 9-Foot Navigation Channel Project.

A better known example of the advantages of more stable UMR water levels is the fact that the Fish Rescue program of the then United States Bureau of Fisheries terminated shortly after inception of the 9-Foot Channel Project. For decades fish had been returned to the UMR from floodplain ponds and sloughs where they had been marooned by river waters falling in summer. Because of the parasitic symbiosis of mussels and their larval hosts, fish rescue was to the mussels' advantage. Stable UMR levels improved opportunity for survival of fishes and parasitic mussel larvae alike.

Increased Shallow-Water Nursery Area:

Nine-Foot Navigation Channel Project impoundment increased the amount of shallow-water area suitable as nursery grounds for mussels and fishes as extensive floodplain flatland was inundated. This creation of eventual shallow-water areas for mussels and fish debatably equals what was available prior to the 9-Foot Channel Project, but there now exist unquestionable mussel nursery grounds, as at Hog Island (see Fuller, 1978b) and the Winona Sites (see Results, above).

Also debatable is whether or not modern nursery grounds are (1) as large a proportion of the UMR as was true in the

pre-project era and (2) well enough developed since overbank inundation about 40 years ago to form refugia adequate for recruitment to the fauna of the main channel and its borders. However, any net losses in nursery beds may be balanced by benefits as a result of stable Pool levels.

Recommendations for Enhancement of the Mussel Resource through Operations and Maintenance Procedures in the St. Paul District

This section provides a list of recommendations concerning how O & M activities and plans might be made to improve mussel life in the Upper Mississippi River. A number of the recommendations concern issues raised in the St. Paul District's O & M Environmental Impact Statement (EIS) (USACE, 1974b), but not all such issues are addressed, because some are irrelevant to the matter at hand or because available information does not warrant an opinion. A recommendation is made only if it seems unequivocally to offer mussels an avenue to substantially improved abundance and faunal variety and it involves activities that are within Corps jurisdiction.

A list of formal recommendations concludes this section of the report; their arrangement follows the order in which their contexts are presented in the following discussion. Some of the contextual discussions contain forceful statements that are relevant to mussel well-being, but are not construed here as being relevant solely to Corps activities. Some of these statements, however, are considered so significant that they are paraphrased as formal recommendations that the Corps become involved in a given issue, but cooperatively with other agencies.

It is unrealistic to assume that the UMR and its benthos can be returned to the pristine conditions of pre-Columbian times, when the UMR mussel community enjoyed the most nearly optimal habitat that it has ever experienced. Nevertheless, certain efforts to enhance the mussel resource are practicable.

Monetary considerations probably will obviate major legislation that would profoundly ameliorate present circumstances. In recognition of this, the St. Paul District's EIS (USACE, 1974b) concluded that destruction of the 9-Foot Channel (i.e., essentially, removal of the UMR locks and dams) was neither imminent nor likely in the foreseeable future. The Academy's recommendations assume that the decision to implement the 9-Foot Navigation Channel Project probably never will be reversed.

A Navigation Channel Depth Other than 9 Feet

A navigation channel depth of less than nine feet could be achieved in two ways; each would have adverse impact upon mussels. Dredging could be curtailed or stopped for a time. The increase of moving bedload would threaten mussels with burial. Alternatively, pool level could be lowered. Shallow-water mussels (including nursery beds) would be threatened by desiccation. Reduced navigation channel depth clearly is undesirable for mussels.

A navigation channel depth of more than nine feet also could be achieved in two ways: by dredging to a greater depth or by raising Pool elevation. Maintaining a 9-foot channel currently involves local dredging to 13 feet. The Academy has observed excellent mussel beds in the main channel at depths only 5 feet deeper than the current maximum dredging depth (i.e., these mussel beds were at about 18 feet). Thus, increasing the maximum dredging depth substantially beyond 13 feet could threaten mussels with removal (or burial by migrating sediment if it were conducted sufficiently close to downstream beds). It should be noted that dredging to a 13-foot depth is conducted in order that a site not be revisited during a given season and that dredging to greater depths is highly unlikely (R. J. Whiting, St. Paul District, USACE, personal communication).

A moderate increase in Pool level probably would not harm mussels, but substantial elevations might, in either or both of two ways. First, at least one investigator (Obeng, 1973) has discovered dangerously low dissolved oxygen (DO) levels at a depth of only 33 feet in a high-dam impoundment. Such phenomena occur under extremely low-flow conditions, which probably do not pertain in the UMR river-lakes. Nevertheless, potential DO problems should be taken into consideration in any plan to substantially increase the River's depth.

Primary photosynthetic production, which ultimately provides both oxygen and nourishment for filter-feeding benthos, such as mussels, is enhanced in the shallows, where solar energy can penetrate turbid UMR waters with unusual effectiveness. This undoubtedly is an important reason why nursery beds develop in certain overbank habitats. Were Pool elevation substantially raised, these beds would be less favored than they are today. Even though nursery beds might begin to appear in the new shallows, reduction in the present ones would create reduced recruitment, which the overall naiad fauna perhaps could not afford.

Increased navigation channel depth, as well as decreased depth, clearly is undesirable for mussels (see Recommendation 1).

A 9-Foot Navigation Channel

The St. Paul District's EIS considered as a third possibility that present channel depths be preserved. The Principal Investigator concurs (see Recommendation 1).

Distribution of Corps Resources

In terms of mussel welfare, the mainstem Upper Mississippi River in the St. Paul District can be divided into three contiguous segments: the Twin Cities, Chippewa, and Recovery Zones. The Twin Cities Zone includes the St. Anthony Falls Pools, Pools 1 through 3, and upper Pool 4 to the confluence of the Mississippi and Chippewa Rivers at the foot of Lake Pepin. The Chippewa Zone includes Pool 4 below Lake Pepin (i.e., "Pool 4A" of Finke, 1966), plus Pools 5 and 5A. The Recovery Zone includes Pools 6 through 10 and probably extends into the Rock Island District, though such a determination is not made in this report.

In the upper two of these Zones the mussel fauna is impoverished almost to the point of eradication, though it exhibits great revitalization below Pool 5A and continues to improve farther down the St. Paul District. It is in this zone of recovery from the adverse effects of pollution and sediment that the Corps can most effectively concentrate resources to improve the mussel resource as promptly as possible (see Recommendation 2).

In the Twin Cities Zone, there is no point in devoting major resources to improvement of the mussel fauna by modifying O & M procedures until present water quality is substantially improved. This view does not suggest that the Corps should or can do nothing in favor of the mussels of this Zone. It does reflect the fact that the Corps has minor jurisdication over the Zone's principal environmental problem, water quality, and therefore at present the Corps' efforts to improve mussel well-being are better directed to where there already exists a fairly healthy mussel community.

Nevertheless, there is an important role that the Corps can play on behalf of mussels in the Twin Cities Zone. Evaluation, followed by authorization or denial, of many applications for permission to modify the UMR is within the Corps' jurisdiction under sections 10 and 13 of the 1899 Rivers and Harbors Act. Scrupulous treatment of these applications could assist the National Pollutant Discharge Elimination System (NPDES), administered by the USEPA under section 402 of P.L. 92-500, in improving water quality, riverbed composition, and shoreline habitats and thus could help prepare a favorable environment for mussel colonization (see Recommendation 3).

In the Chippewa Zone, also, there is a single dominant problem that influences mussels adversely: Chippewa River sediment. Some of the potential measures for control of erosion in the Chippewa and neighboring watersheds are well within Corps jurisdiction and must be considered if there is to be a reduction of moving bedload (see Recommendation 4). The trapper-damming of a few selected streams such as the Chippewa is mentioned in Recommendation 4. Such action is considered practical because its implementation is within Corps jurisdiction and would trade minor ecosystematic disturbance for a major benefit to benthic life, i.e., elimination of the majority of UMR bedload in the St. Paul District (the Chippewa alone contributes more than half the total). This trade-off is in the best interest of freshwater mussels. However, even if a trapper dam project were feasible and implemented, it would not eliminate UMR bedload problems, for two principal reasons. First, material already in the river would continue to move down-basin. Failing to escape the locks and dams, it would collect at the lower ends of the Pools, where, influenced by currents, it would remain in motion, still changing the topography of the river's floor. Second, its place in the upper parts of the Pools would be taken by materials newly eroded within the river itself because the carrying capacity of its water would be partially unsatisfied as a result of the elimination of extrinsic sediments. Thus there would still be moving bedload. As long as the UMR remains impounded and/or large-vessel shipping continues, channel-maintenance dredging will persist. This discussion assumes that the locks and dams will not be removed and that commercial traffic will not abate. Therefore, dredging is perceived as an essentially permanent feature of this waterway.

Dredging

As already noted, dredging impacts can be divided into three parts: removal of material from the streambed, migration of disturbed peripheral material, and relocation of material.

Removal of Dredged Material

Factors that can be considered in an evaluation of the removal of streambed material include the size of the dredge cut, the instruments penetrating the bed, and the overall dredging plant.

The size of the dredge cut (i.e., in effect, the volume of material removed from the riverbed) is restricted by the authorized dimensions of the navigation channel. The breadth

of the cut may not exceed the breadth of the channel, and within that limitation, is determined by an accumulation of bedload that would impede navigation. Accumulation of bedload determines cut length, also, which can be several miles in areas of extensive shoaling (as at the Weaver Bottoms Complex Site), but usually measures only a few hundred yards. Because, as discussed earlier in this report, mussels are so unlikely to prosper in shallower portions of the channel, cut breadth and length offer little potential for damaging these animals.

In contrast to length and breadth, however, cut depth is a debatable issue that has excited considerable controversy. The Corps commonly dredges the 9-Foot Navigation Channel to a depth of 13 feet, in order to reduce dredging frequency. There is no doubt that increased dredging depth can decrease dredging frequency. In areas of heavy shoaling, it is probable that dredging will remain perennial, but that it can be reduced to one action per year; in areas of lesser shoaling, it is possible that increased dredging depth could sharply reduce dredging frequency. Primarily for reasons that do not include channel-maintenance dredging, the UMR mussel fauna is in decline, but certain species still use the navigation channel for at least some portion of their life cycles (usually as juveniles). Relatively infrequent disruption of the main channel habitat obviously enhances this portion of the mussel resource, if only to the extent that some juveniles may eventually escape the channel and grow to reproductive maturity in its borders. Juveniles that exploit the main channel apparently do so on rafts of vegetable detritus, which perhaps enable young mussels to be ferried on moving bedload out of the main channel and into less disturbed parts of the river.

In the relevant literature there are speculations (Heard and Guckert, 1971) or even claims (Utterback, 1928) that certain mussel species are hypertacytictic, i.e., capable of producing more than one brood per year. (These assertions have not been corroborated subsequently.) Most mussels breed annually at most, and individuals more than one year old probably are too heavy for rafting and must burrow into the riverbed lest they be swept away and die on account of constant disturbance by the current. Such disturbance elicits the normal reaction of closing the shell, and the animal eventually dies of asphyxiation and/or starvation. Probably only the annual set of mussel juveniles must be taken into account in any attempt to guide environmentally sound channel-maintenance dredging schedules. It seems reasonable to suggest that dredging no more frequently than once per year is a practical safeguard against damage to UMR mussels that can live in the navigation channel (see Recommendation 5).

The St. Paul District operates two dredging plants, the Dredge WILLIAM A. THOMPSON and the Derrickbarge HAUSER. The THOMPSON uses a cutter head, of which there are few varieties; the Hauser uses a clamshell bucket. In terms of reduced impact on mussels during removal of streambed material, neither plant is clearly superior to the other.

Migration of Sediments Disturbed by Dredging

Some sediment is resuspended when material is removed from the riverbed, regardless of the type of equipment used. This sediment migrates some distance before it resettles. Thus there is a possibility that mussels downstream from the dredging site could be buried. Elimination of this sediment migration is desirable in theory, but has not yet proven possible in practice. For example, the Corps has found silt curtains of little or no value in the riverine environment.

On the other hand, Corps studies have indicated that, in certain respects, migration of sediments disturbed during dredging is a rather limited problem. First, plumes of suspended solids in concentrations above ambient levels have not been detected farther than 1,000 feet downstream from dredging operations. Second, disturbed sand resettles close to the dredge cut. Third, finely divided materials ("fines") do not measurably settle out in the river current, but are diluted to ambient concentrations. Fourth, only on the outermost fringe of the dredge cut does resettlement of material approach a depth of three inches.

The Academy always conducted mussel surveillance for at least one quarter of a mile (1,320 feet) downstream from a proposed dredge cut and found no evidence of mussel beds in this reach. Thus it appears that damage to mussels in the main channel on account of present Corps dredging is minor if it occurs at all. It is possible, of course, that some development of a mussel bed could have occurred in the channel at a site that had not been dredged for many years. No relevant example is known to the Principal Investigator.

Most of the dense UMR mussel assemblages are found in the channel borders. Less dredge-disturbed matter would fan out into the borders than would travel directly downstream from a cut. Therefore, damage to mussels in the channel borders probably is very unlikely.

The impact upon mussels in the channel borders from redeposition of dredge-disturbed sediments cannot be reliably assessed on the basis of currently available information. However, Marking and Bills (1977), in contrast to earlier reports (e.g., Ellis, 1936), found that mussels can tunnel upward to reach the water column through as many as three inches of sediment. These two authors' experiments concentrated on *Fusconaia flava* and two subspecies of *Lampsilis* (*L. radiata siliquoidea* and *L. ovata ventricosa*). Members of *Lampsilis* consistently are active, not very dense animals, which rather easily can escape sedimentary inundation, but *F. flava* is comparatively inactive and dense. Marking and Bills demonstrated less successful escape from sedimentation by *F. flava*. Their results can thus be interpreted in terms of the relative mobilities of their experimental subjects. However, it is important to note that these subjects were tested in *unstable* substrates (sand, mud, silt, etc.), which are unfavorable substrates for mussels. Most mussels are found in stable substrates such as gravel or viscous mud. It is unlikely that even the active *Lampsilis* could have escaped the resettling "fines" had they been tested in such stable substrates. A thorough assessment of the impact upon freshwater mussels of inundation by redeposition of streambed materials awaits further study.

As described above, reduced dredging frequency is to the advantage of the mussel resource. However, lesser frequency implies that more material may have to be removed when dredging does occur. A larger dredge cut causes increased sediment migration and a greater threat of mussel burial elsewhere. This point suggests that increased dredging frequency is to mussels' advantage. A choice between (1) lesser, but more frequent sedimentation and (2) more copious, but less frequent sedimentation cannot be made on the basis of existing experimental evidence, i.e., the work by Kaskie (1971) and Marking and Bills (1977). However, until definitive information is available it appears desirable to compromise between minimizing dredging extent and minimizing dredging frequency (see Recommendation 5).

It is clear that there remain unresolved problems concerning the advantages and disadvantages to mussels in regulating sediment migration. Fortunately, these problems may be academic for Upper Mississippi River mussels at present. As established previously, migration of material disturbed (but not removed) during dredging and possible burial of mussels downstream do not seem to jeopardize these animals.

Relocation of Dredged Material

The third and final step in the dredging process is relocation of the dredged material. Relocation has three principal aspects: selection of the disposal site, transportation of the material between the dredge and the site, and treatment of the deposited material.

Selection of disposal sites probably is the most difficult problem confronting the St. Paul District in its efforts to reconcile dredging with environmental well-being, including the welfare of the mussel resource. A disposal site is either aquatic or terrestrial; an aquatic site is in either open water or a backwater. Each alternative offers its special problems.

Open-water disposal creates artificial shoals that are readily eroded by wind and/or water. Artificial shoals in backwaters are less vulnerable to erosion, but in either case burial of nearby benthos, including mussels, can result. Admittedly, one of the criteria for disposal site selection is the ability of the area to resist secondary movement of dredged material, and approximately 80% of all deposited material, including much open-water disposal, has not moved from the area where it was originally placed (R.J. Whiting, St. Paul District, USACE, personal communication).

On the other hand, aquatic disposal of dredged material can create productive habitat(s) for wildlife in general. For example, disposal in certain extensive backwaters (notably the Weaver Bottoms) can create terrestrial dikes that reduce erosion by both wind and water in the immediate vicinity, and this would increase stable shallow-water benthic habitat. Such developments obviously are desirable because of the value of shallow-water nursery beds of mussels (especially opposite Winona, Minnesota, and (Fuller, 1978b) at certain of the "Green Bay Sites" in Pool 19).

It is clear, then, that aquatic disposal can be practiced beneficially. An important part of any decision to do so is site-specific surveillance to determine potential impact on existing benthos (see Recommendation 6).

In contrast, terrestrial disposal offers no threat to mussels unless slumping of the "spoil bank" is not forestalled. Proper treatment of relocated dredged material is addressed below.

Once a site for deposition of dredged material has been selected, the dredged material must be transferred there from the dredging site(s). When the THOMPSON is the dredging

vessel, transportation of sediment (in a slurry) is a one-stage operation that brings the material directly onshore through pipe.

In the case of the HAUSER, however, transportation has sometimes been a two stage process. "Dredged material is transported close to shore by barge, dumped in the shallows, and then redredged onto land. It is very hard for a crane to skim the material from any inshore mussels thus buried. The usual result is that they either remain buried or are dredged onto land, both possibilities leading to death" (Fuller, 1978b). Current practice in the St. Paul District is to unload directly onto land in a one-stage process that eliminates shallow-water dumping (see Recommendation 7).

Most proposed disposal sites have been used in the past and probably are devoid or nearly devoid of mussels on account of the high level of associated human activity, especially if two step disposal was practiced. The Upper and Lower St. Anthony Falls Pools are examples of areas where disposal can presently occur without regard to the well being of mussels. In the case of historical sites or newly proposed sites where there is reason to suspect the presence of mussels, preliminary search for these animals is advisable (see Recommendation 7). Mussel surveillance should be contemplated even in barren areas if there has been substantial improvement in the quality of water and/or streambed for several years (i.e., long enough to permit recolonization by environmentally sensitive benthos, such as mussels).

Treatment of relocated dredged material is the third and last step in determining its eventual role in the UMR ecosystem. Control of aquatic deposits is scarcely possible, but control of material on land is possible and varied.

The most important consideration in mussel well-being is that the material never make its way back into the river. This can be accomplished in several ways. First, dredged material can be placed so far from the river that it cannot return without extraordinary meteorological and/or human intervention. Second, dredged materials can be deposited in depressions or even pits already prepared by bulldozer or other land moving equipment. Third, erosion-control structures can be introduced to a site (pilings, fencing, etc.). Bank protection can be installed, no doubt principally in the form of riprap, but vegetation ultimately is equally as valuable (see Recommendation 8).

Revegetation of dredged material deposits can do much to reduce reentry of sediment into the UMR. The key to

successful revegetation is to plant with species that will provide ample rootstock and are appropriate to the ecotone. Erosion of dredged material deposited in floodplain forest, for example, cannot be stemmed by shade-intolerant vegetation. The seasonality of seed germination and survival of seedlings also must be considered. For example, early-season spoil cannot be successfully broadcast with seed that will sprout only under drier conditions later in the summer.

Studies such as those by Howe (1980) and Swanson (1976) should be consulted for additional details and evaluations of possible revegetation practices. Successful colonization of dredged material by plants is dependent upon moisture. Seeding is economically superior to replanting, but the usefulness of either practice is debatable because availability of moisture is so difficult to predict. Human attempts at revegetation often are no more successful than natural colonization, which can proceed rapidly. Only three years may be required for development of a climax plant community. Observed climax communities have persisted unchanged for more than 20 years. In the event that moisture availability can be confidently foreseen, best revegetation is attained by using species that spread rapidly and have broad, deep root systems. Such plants best survive dry periods and best stabilize deposited material. Certain woody species (e.g., cottonwood, willows) provide the greatest stability. (These remarks essentially are an abstraction of a lengthy personal communication from J.S. Howe, Southern Illinois University at Carbondale.)

The theme of timing O & M activities is additionally illustrated by the question of whether dredging could be scheduled so as to minimize disturbance of protected mussels during the period of the year when, as species, they are most vulnerable, i.e., when they are gravid. Discussion of this possibility depends only upon Higgins' Eye (*Lampsilis higginsi*) because nothing is known of Fat Pocketbook (*Proptera capax*) breeding in the UMR.

Higgins' Eye is bradytictic, i.e., a long-term breeder that typically is gravid throughout most of the year except early summer. For example, Surber (1912) reported Higgins' Eye gravid in May and September. It is probable that Surber's observations were made on UMR animals obtained near the Bureau of Fisheries mussel propagation laboratory at Fairport, Iowa, now in Pool 16 of the Rock Island District. Therefore, somewhat to the north, as in the St. Paul District, the months of Higgins' Eye gravidity reported by Surber probably would extrapolate as June and October. On the other hand, the Academy found *Lampsilis higginsi* gravid in the St. Paul District in both July and August. Consequently,

it is possible that this species could be gravid somewhere in the St. Paul District at any time during the dredging season.

More research is needed to determine whether there is a clear-cut pattern to the timing of the Higgins' Eye life cycle within the St. Paul District. If so, it would be desirable to attempt scheduling dredging at a given site at a time when local Higgins' Eye were not gravid.

Wing Dams and Riprap

Within the St. Paul District, wing dams offer most of the little rocky benthic habitat that is available. They are therefore valuable as providers of habitat for lithophilic, rare mussels such as Spectacle Case, *Cumberlandia monodonta*, and Salamander Mussel, *Simpsoniconcha ambigua*.

In addition, there is much circumstantial evidence that wing dams are an important substrate for other macroinvertebrates and thus an important resource for the UMR recreational and commercial fisheries (see USACE, 1974b).

In view of the probable importance of wing dams to rare, lithophilic mussels and to UMR fisheries, several actions are in order. First, existing wing dams should not be destroyed. Second, wing dams should be repaired as needed, unless the repair process promises to do significant biotic damage. Third, in order to facilitate such determinations, a survey of the physical and biological properties of existing wing dams in the St. Paul District should be conducted. Fourth, any O & M activities that threaten wing dams (e.g., removal as part of an hydraulic improvement program) should not proceed until after biological surveillance in search of rare mussel species inhabiting the wing dams has been completed.

Submerged riprap may be just as beneficial as a source of lithic habitat for benthos as wing dams. In Pool 13, for example, near Savanna, Illinois, Academy surveillance in 1977 found an excellent mussel community in riprap at the base of a railroad embankment. Precautions cited above with regard to disturbing wing dams should be observed in the case of riprap, as well (see Recommendation 9).

Fishways

Most mussel life in any waterway is dependent upon the well-being of the ichthyofauna because fishes host unionid larvae (glochidia) as parasites after expulsion from the

adult female clam. Unfortunately, UMR modification by dams, which began long before the 9-Foot Navigation Channel Project, profoundly affected the movements of fishes (the Project essentially only aggravated an existing, unfavorable situation). The ranges of anadromous (and other migratory) fishes have been restricted, and some species have been extirpated in the UMR. The impact of locks and dams upon the mobility of fishes and upon the vagility of their mussel parasites is poorly understood. Some reports have concluded that the impediment is small or non-existent, but these studies concentrated on recreational and/or commercial species of fish. It is true that some of these species are important mussel hosts, but other species, also hosts, have not been studied in this context. Further relevant studies are needed before the impacts of locks and dams upon fishes and mussels can be generalized.

The impact is clear, however, in the previously cited case of the anadromous Skipjack Herring, which was essentially excluded from the UMR above Pool 20 when the Keokuk Dam was constructed in 1913. This loss was responsible for extirpation of Ebony Shell (*Fusconaia ebena*) and probably Elephant Ear (*Elliptio crassidens*) above Locks and Dam 19. The former was once the most valuable commercial mussel and comprised perhaps the majority of naiad biomass in the River. Destruction of even one mussel species of such value is ample justification for investigating ways to reduce the impediment to fish movement that locks and dams present.

Fishways of various sorts might be considered, or lock gates might be left open when craft are not passing through. This report intends no essay on the subject and offers only a simple recommendation (10) in the interest of the mussel resource and general ecosystematic health.

Mussel Bed Relocation

Proposed UMR modification sometimes involves a reach where a mussel bed occurs. The question whether the bed might be moved logically arises in pursuit of a compromise between destroying the bed and stopping the project. Moving organisms to another habitat involves definite risks, but can be acceptable as an alternative to certain destruction if a few simple precautions are taken.

First, a suitable alternate site for the bed must be identified. Fortunately, as this study's field work has made clear, there still are viable UMR mussel beds and associated habitats within the St. Paul District, chiefly in Pools 9 and 10.

Second, the mussels to be transplanted must be gently removed from the streambed. This is best accomplished by hand and by diver. Other methods of capture are unacceptable because they may cause physical trauma that could induce abortion. All alternatives to diving not only are destructive, but also do not recover all available animals. For example, one widely used alternative technique is brailing, which the Academy employed more than any other method during the present survey. In this work, however, only a synopsis of the fauna was intended, and damage or destruction of the few was deemed unfortunate, but justifiable investment in knowledge of the many. In mussel bed relocation the objective is very different, i.e., to recover *all* animals safely.

Third, the animals must be protected from asphyxiation, desiccation, and thermal shock while being transported between sites. Movement between any two points within the 9-Foot Navigation Channel Project and the St. Paul District is not more than a day's travel overland, which is by no means an excessive period of time out of habitat water in the case of bivalved animals that can seal themselves from the external environment as well as mussels can. Thermal insulation can be provided by shipping mussels in moist sacking and in coolers and/or an air-conditioned vehicle. Ice can be introduced to the coolers in order to reduce ambient temperature, and this can be very desirable in hot weather, but the animals must not come into direct contact with the ice, in order to avoid thermal shock. Similarly, the animals must not be transported in the presence of great moisture, because under those circumstances they will attempt respiration and probably will asphyxiate. Mussels can be transported in tanks of well aerated water if water temperature is controlled. In this case, the animals must be properly oriented (see Appendix E) in a stable material (e.g., fine gravel, coarse sand) so that they do not roll about the floor of the tank. This rather violent disturbance could cause abortion of any gravid females in the shipment. Transport in insulated, cool moist sacking is equally safe and much more economical.

Fourth, the animals must be properly restored to aquatic habitat at the new location. As in the case of removal from the original streambed, the mussels must now be handled by divers, once again to avoid the consequences (notably abortion) of mechanical trauma. The divers must place the animals directly into the new streambed; simply to hurl the mussels into the water is to invite their demise (see Imlay, 1972). The correct orientation of a mussel in its substrate is shown in Appendix E.

Fifth, the location of the mussel's replacement must be marked in such a way that the site can be readily revisited

to investigate the animals' well-being. This is necessary because mussel bed relocation is in its infancy and further evaluation is imperative before this technique can be implemented with complete confidence (Recommendation 11).

Dense mussel assemblages and reproductively valuable nursery beds can occur in water shallow enough to make the mussels vulnerable to damage from beaching of river craft. The Corps can contribute to the well-being of mussels, other benthos, and shallow-water biota by regulating beaching so as to minimize such damage (see Recommendation 12).

Research

The possibility that the Corps might conduct its own UMR mussel surveys raises some questions. What methodology is to be employed? Where are "great beds" and Endangered Species likely to be found in the St. Paul District? Is there a "critical" bed size, i.e., a population density that serves as a threshold below which there is no need for mussel surveillance, because the probability of encountering legally protected species is negligible?

The materials, methods, and procedures employed by the Academy (see Methodology, above) are sufficient to the Government's needs. Some locations of legally protected mussel species have been treated (see Species-Group Mussel Taxa discussion above).

Locations of "great beds" of mussels in the St. Paul District are somewhat more equivocal. Three examples were revealed during this study: the Whisky Rock bed immediately below Lansing, Iowa (Pool 9); small, discontiguous, but dense beds in Wisconsin waters shortly below Locks and Dam 9 in Pool 10 (see discussion of the Hay Point Bank Repair Site in Fuller, 1978b); and the beds in the vicinity of Prairie du Chien, Wisconsin, and McGregor, Iowa (see discussions of the Prairie du Chien East Channel and McGregor Sites, above).

In addition to these discoveries, an inventory of all extant mussel beds in the St. Paul District should be undertaken by the Corps in an effort to reduce the chance of O & M activities' inadvertently damaging Endangered Species as occurred in the UMR East Channel at Prairie du Chien in 1976 (see Recommendation 13).

The matter of determining a "critical" size and/or density of a mussel bed is far more equivocal. The goal of this notion is to develop simple numerical discriminants that could be used as guidelines to indicate whether work could

proceed with impunity at a given site. Such a goal is contrary to nature, of course, as illustrated by discovery at the Brownsville (Minnesota) Site of a freshly killed *Lampsilis higginsi* on a bank of material dredged just after the Academy had finished an especially thorough survey (see Fuller, 1978b). The results of the present study argue that legally protected mussels are rare indeed, but that they could occur more widely in the St. Paul District than is presently realized, especially in Pools 9 and 10. Establishing "critical bed size" can be accomplished only on a "case-by-case" basis if it can be done at all and is a dubious endeavor at best. This means that the Government cannot avoid the necessity of environmental surveillance when and where there is suspicion of Endangered Species among the benthos.

The St. Paul District can provide much of the necessary surveillance by using its own staff, which includes biologists who are suitably experienced, partly as a result of site-visits to coordinate with the Academy field crew. The staff's one relevant weakness is lack of taxonomic expertise sufficient to unequivocally identify an Endangered mussel species. This difficulty can be remedied with the help of an appropriate malacologist, so an entire consulting team should not be necessary in the future (see Recommendation 14).

Research into such topics as the biotic significance of wing dams (see Recommendation 9) and the locations of major St. Paul District mussel beds (see Recommendation 13) will help the Corps achieve self-reliance in most mussel investigations.

The Recommendations

Some of these recommendations can and should be implemented solely by the Corps. Others probably can be implemented only through interagency cooperation. Some should be implemented only with the help of outside consultation, on at least some occasions. A few should be implemented only on a "case-by-case" basis.

1. Changing the depth of the navigation channel would be to the disadvantage of mussels and should not occur.

2. In the immediate future a disproportionately large share of the Corps' efforts to improve the UMR mussel resource should be devoted to the Recovery Zone, where there remains a comparatively thriving mussel community.

3. In the Twin Cities zone of UMR mussel life, the Corps should uphold extant regulations regarding UMR modification (construction, influent discharge, etc.),

as in permit application evaluation, to help in preparation of congenial mussel habitat so that specifically O & M activities eventually can aid in development of that natural resource.

4. In the Chippewa Zone the Corps should make every reasonable effort to reduce UMR sediments from the Chippewa River and neighboring watersheds (e.g., the Zumbro). For example, bank repair, construction of holding dams at tributaries' mouths, and coordination with other agencies (as in public education) are appropriate considerations.

5. Navigation channel dredging should penetrate to the minimum depth that would ensure that a site be dredged no more than once a year.

6. Open-water disposal of dredged material should be avoided; in certain areas backwater disposal, preceded by biological surveillance, can benefit mussels.

7. One-step transport of dredged material to the disposal site should always be practiced unless prior surveillance has established the absence of mussels that would be injured by shallow-water dumping during two-step disposal.

8. Return of dredged material to the River should be prevented by any environmentally sound means.

9. UMR rocky habitats of all kinds should be conserved. Alterations to wing dams should not be conducted without prior biological surveillance.

10. The Corps should investigate whether modifications in structure and/or use of locks and dams could aid in restoring mussel host fishes to their pre-impoundment geographic ranges.

11. Safe relocation of mussel beds should be conducted as an alternative to their destruction.

12. The Corps should consider regulating the beaching of commercial and recreational craft to minimize damage to shallow-water benthos such as certain known mussel assemblages.

13. The Corps should inventory UMR mussel beds, not only in the St. Paul District, and perhaps in cooperation with other agencies.

14. The St. Paul District should now conduct its own mussel surveillance. Consultation with an appropriate malacologist will sometimes be required.

SUMMARY

The Academy of Natural Sciences of Philadelphia has conducted a three-year field study of Upper Mississippi River (UMR) freshwater mussels. This survey was complemented by laboratory and library investigations. The entire project was undertaken on behalf of the St. Paul District, United States Army Corps of Engineers, in order to gather information about legally protected mussel species and others that are in jeopardy.

Field work occurred in 1977 (mid-July through mid-November), 1978 (mid-July through late October), and 1979 (June and early July). Its principal goal was to survey the mussels at selected Sites of channel-maintenance dredging and/or other Operations and Maintenance (O & M) activities in order to establish, at a high level of confidence, that protected species were present or absent.

Each Site was selected by the Corps, although advice by the Principal Investigator influenced those decisions on certain occasions. The decision to survey a given Site was based on its history of frequent and/or extensive dredging, the possibility of other O & M activities in the vicinity, and/or the suspected presence of legally protected mussels.

The 1977 field work took place in the Corps Rock Island District, as well as the St. Paul District, and has been reported (Fuller, 1978b). The 1978 and 1979 field work was confined to the St. Paul District. Rock Island District data are not repeated here.

The portion of the three-season study area that is relevant to this report consists of certain navigable reaches of four UMR drainage rivers (the Minnesota, St. Croix, and Black Rivers and the UMR itself) whose channels lie within the St. Paul District and are maintained by the Corps, i.e., the present study area is that District's share of the 9-Foot Navigation Channel Project. The 4-Foot Navigation Channel of the Minnesota River and all waterways in the Rock Island District are not discussed here.

The Academy's field crew conducted mussel surveillance at over 100 Sites in the UMR, three Sites in the Minnesota River, four in the St. Croix, and none in the Black River (the literature was searched, however, for Black River data).

The Sites were usually surveyed by brailing; collections by hand and with Needham scrapers were occasionally made in water too shallow for brailing. SCUBA and HOOKAH diving were

used only to search for rare taxa in mussel beds and to replace rare taxa *into* the riverbed. Over 10,000 living mussel specimens were collected and examined. These results provide a large data-base for comparisons between and among taxa and locations within the study area.

The Upper Mississippi River had an abundant and diversified mussel community in the late 19th Century, before the heavy losses caused by the pearl button industry during the period from about 1890 through about 1920. In 1977 through 1979 there were unquestionably far fewer mussels than there had been in the late 19th Century. Mussels were nearly or fully extinguished from the St. Anthony Falls Pools and Pools 1 and 2. Limited recovery occurred in Pools 3 and 4. The fauna improved increasingly through the Pools below.

The Academy's observations reveal that the following three Zones within the mainstem UMR can be distinguished on the bases of their suitability for mussels and their actual mussel faunas. The Twin Cities Zone (the St. Anthony Falls Pools, Pools 1 through 3, and upper Pool 4 to the foot of Lake Pepin) is characterized by inferior water quality and a near absence of mussels. The Chippewa Zone (Pool 4 below Lake Pepin and Pools 5 and 5A) exhibits unusually heavy bedload, mostly emanating from the Chippewa River, and a very sparse mussel fauna. The Recovery Zone (Pools 6 through 10 and probably much of the upper Rock Island District) has much less bedload, improved water quality, and a comparatively healthy mussel fauna.

Mussel populations of the lower Minnesota River, which had been diversified and abundant in the late 19th Century, appeared to be completely extinguished in 1977, when the entire 9-Foot reach of the Minnesota was thoroughly surveyed.

Historical changes in mussel populations of the lower St. Croix cannot be reliably assessed because of the inadequate quantity of published locality records. However, it is clear that 1977 and 1978 records for one Site studied by the Academy (i.e., Hudson RR Bridge) compare very favorably with the historical ones for the entire river; indeed, Hudson is one of the two locations in the entire study area where the Academy found living examples of the Endangered *Lampsilis higginsi*. Unfortunately, this species was not found elsewhere in the St. Croix River. In 1977 and 1978, surveillance of the St. Croix was completed in the sense that *all* historical channel-maintenance dredging sites were investigated. Mussels were plentiful only at Hudson and in only a single bed. Clearly, the Academy's earlier report (i.e., Fuller, 1978b) implied undue optimism about the mussel resources of the lower St. Croix River; in fact, they have been badly damaged.

Although the Academy did no field work in the Black River, there are some recent data (Exhibit 97) on mussels in this

portion of the study area; specifically, Havlik (1978a) found an assemblage of living mussels that compares favorably with the better mussel communities observed by the Academy elsewhere in the study area.

Although the *absolute* abundances of most (and probably all) mussel species in the Upper Mississippi River basin have declined during the last 75 years, *relative* abundances have frequently stayed much the same. One of the exceptions to this trend is *Quadrula quadrula*, the Mapleleaf, which is a dramatic example of an animal that has exploited the impoundment habitat.

An unfortunate number of species are in decline and facing extinction in the Upper Mississippi drainage. Conspicuous examples of mussels whose ranges and numbers have been greatly reduced are *Tritogonia verrucosa*, Buckhorn; *Plethobasus cyphyus*, Bullhead; and *Elliptio crassidens*, Elephant Ear. These animals are not among the historically more common in the drainage. It is probable that they and other currently rare mussels were first propelled into decline by the pearl button industry, which reduced their populations to such an extent that reproduction could no longer offset even natural mortality. During the intervening years, environmental degradation increased, contributing to their decline. In 1977 through 1979 they were evidently below recruitment level in the study area.

The most dramatic examples of the declining mussels, of course, are the two legally protected Endangered taxa that are recognized as valid species in this report: *Proptera* (often *Potamilus*) *capax*, Fat Pocketbook, and *Lampsilis higginsi*, Higgins' Eye. Another species of grave concern is *Cumberlandia monodonta*, Spectacle Case, which may soon receive nationally Threatened status. No traces of *P. capax*, *C. monodonta*, or the rare *Leptodea leptodon* and *Simpsoniconcha ambigua* (Narrow Papershell and Salamander Mussel, respectively) were found in the St. Paul District. The Academy encountered *Lampsilis higginsi* alive at two Sites. (A recovery program for Higgins' Eye probably would be successful.)

In addition to the thousands of specimens shipped to the Academy for permanent curating as vouchers of this study, hundreds of *Amblema plicata* (Threeridge) were taken, examined, and then replaced alive. At some Sites the numbers of Threeridge could only be estimated. In terms of abundance estimates based on brailing data, this species emerged as the dominant UMR mussel.

This last notion has been corroborated by several recent studies. Nevertheless, *Amblema plicata* probably is not the

most plentiful UMR naiad. First ranking probably belongs to the Fawnfoot, *Truncilla donaciformis*, which is not effectively collected by brailing because of its small adult size. However, juvenile Fawnfoot are caught on the brail (by the byssal threads) far more often than any other juvenile species. Also, during pollywogging in the mussel nursery beds opposite Winona, Minnesota, the Academy found Fawnfoot to be twice as common as Threeridge.

It is apparent that young mussels with byssal threads (e.g., *Truncilla donaciformis*) can slide along the surface of moving bedload because their byssi unite with low-density materials (e.g., deliquescent vegetable matter) to form rafts. The adult, less mobile and more dense, is buried more readily by moving bedload.

As mentioned earlier (Fuller, 1978b):

> Juvenile data can also provide insight concerning a species' reproductive capability. It is encouraging that juveniles of many species *were* found. Also, the population structures of many mussel species gave evidence of recruitment.

The success or failure in the study area of many mussel taxa is updated from the previous report (Fuller, 1978b) where recently available data permit.

The ecological setting, such as streambed type, current velocity, water depth, and larval host(s) of the various mussels, is reviewed in an effort to define the habitat requirements that promote the well-being of the various taxa. Very few taxon-specific habitat requirements can be stated. There apparently are two reasons.

First, the "state of the art" is genuinely impoverished. Only in the matter of larval hosts is there much relevant taxon-specific information (reviewed by Fuller, 1974, 1978b).

Second, only a few UMR streambed types are consistently inhabited by mussels. Gravel, viscous mud, and, to a lesser extent, hard-packed sand are preferred by all species except (1) certain ones of low body density (notably the several *Anodonta*) that tolerate and even exploit fine muds; (2) the deep-burrowing *Proptera laevissima*, which can survive in unstable sand, even in the main channel; and (3) the jeopardized, lithophilic species *Cumberlandia monodonta* and *Simpsoniconcha ambigua*. A comparatively healthy modern mussel bed exhibits about two dozen species living together in the same substrate. The only requirement is that the substrate be stable. Other factors necessary in good mussel habitat are few, simple, and common to all species. Water depth must be sufficient to preclude

high temperatures and desiccation at times of low river levels. Current velocity must be great enough to convey ample oxygen and food (plankters).

It thus appears that, in terms of fundamentally important physical and chemical factors (including nutrition), most UMR mussels experience the same needs. The one area in which they seem to partition the study area's resources is glochidial parasitism of hosts, mostly fishes.

Because the UMR ichthyofauna, also, has been disadvantaged by impoundment, this host-parasite relationship, crucial to the welfare of UMR (and other) naiades, may deteriorate in the future. This development would cause almost irreversible damage to the mussel fauna.

The impact of the 9-Foot Navigation Channel Project in the St. Paul District upon mussels is evaluated by weighing it against other possible causes of the general decline in abundance and diversity of this fauna since the pre-Project period. The major adverse impacts appear to have been the pearl button industry and generally declining water quality. Other agents include prior channel modifications, restriction of host fish ranges by the Keokuk Dam, and possibly the presence of the Asiatic clam, *Corbicula fluminea*.

The effects of impoundment itself are assessed by comparing conditions in the modern UMR to the early stages of development in several deep-water impoundments. The main impacts of impoundment appear to be a shift to limnophilic species, reduction in rooted macrophytes, certain food chain changes, decreased dissolved oxygen in some deep areas, and increased shallow water areas.

Nevertheless, perpetuating impoundment offers benthic life some advantages. A stable water level and increased nursery grounds are the most important of these.

The main impacts associated with the navigation channel itself are related to dredging. The proper disposal of dredged material is far more significant than possible impacts from the dredging plant itself or from redeposition of sediments resuspended, but not removed by the dredge. Although channel-maintenance dredging is acknowledged as an important source of adversity for mussels, other factors are here considered more serious. As reported by Fuller (1978b):

> The field observations of mussel populations and their relationships to channel dredging by the Corps in the Upper Mississippi River [drainage] indicate that this dredging has had only a minor impact on Endangered or other mussel species.... The losses in

mussel populations observed in this study are apparently due to several factors in addition to the influence of Corps dredging. These factors include municipal, industrial, and agricultural wastes (the Twin Cities and the Minnesota and Des Moines Rivers are especially important sources); increased bedload, as from the Chippewa River; inadequate glochidial host opportunities (the classic victim is *Fusconaia ebena*, the Ebony Shell); scattered point sources, such as isolated power plant effluents; disease induced by microorganisms (Ellis, 1931b) and, perhaps, by unionicolid mites; dredging and disposal of riverbed material by the private sector; increased sedimentation caused by 9-Foot Channel Project impoundment; and, potentially as threatening to mussels as any of these other factors, the recent appearance in the study area of *Corbicula fluminea*, the Asiatic clam.

For some of these problems the 9-Foot Navigation Channel Project and O & M activities bear no responsibility at all. Biocides, as a final example, will be the most dangerous enemies of mussels in the years to come.

Any of these types of adversity will do the greatest damage to the species that already are the least abundant, including the Endangered *Proptera capax* and *Lampsilis higginsi*. The Fat Pocketook probably is extinct in the UMR, and Higgins' Eye, as noted above, was found alive at only two Sites in the St. Paul District. Other mussel species are equally rare.

Recommendations for enhancement of the mussel resource through Operations and Maintenance procedures in the St. Paul District are made. They relate primarily to the disposal of dredged material, although several other specific points are addressed.

There can be no doubt that the UMR mussel fauna is in decline. Nevertheless, careful management can still preserve for the UMR its important freshwater mussel ecosystematic resource. Especially because mussels provide copious physical substrate for many components of the food web, this objective is just as important as the conservation of Endangered Species.

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The Principal Investigator wrote this report, which was edited principally by D.H. Snyder and refereed by James M. Engel (USFWS), Pamella Thiel (WDNR), T.O. Claflin, Robert J. Whiting (USACE), and James L. Peterson and John W. Sherman (ANSP). The typing was performed by Cheryl A. Brooks, Patricia Ferguson, James L. Gollin, and Eleanor L. Thomas. Marianne Phillips proofread the Final Report. E.L. Thomas supervised production of the Draft Preliminary, Draft Final, and Final Reports. Mary H. Fuges and Diane Whiting created the original drawings.

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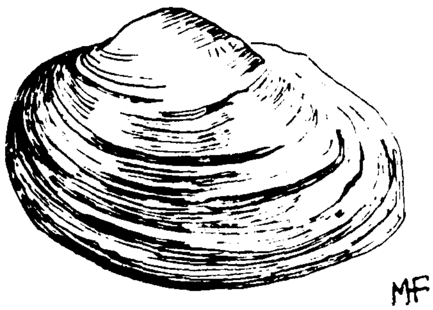
Any person whose contributions were exceptional, but are not mentioned above, were omitted inadvertently, at the fault of the Principal Investigator, who accepts responsibility for any other shortcomings of this document.



Fawnfoot (male)

Truncilla donaciformis (Lea)

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In a few instances (e.g., Fuller and Hartenstine, 1980), this list updates references in Fuller's (1978b) earlier bibliography.

Compilation of this bibliography was halted 29 August 1980.

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GLOSSARY

The words and expressions defined below are drawn from the many suggestions made by Corps, Academy, and other personnel who have acted as editors and referees of this report (see Acknowledgments). Most of the suggestions have been adopted. Those that were not are of two categories. The first is highly technical terms (e.g., "roller gate") peculiar to Corps activities and rarely encountered by the public; moreover, such terms are not readily understood without lengthy explanation and some illustrations. The interested reader might consult Tweet (1975), for example, for such explanatory material. The second group of omissions from this glossary consists of words (e.g., "deliquescent") that may be unfamiliar, but occur in any good dictionary of American English, such as Webster's New International Dictionary, second or third edition (the second is the superior of the two). Aside from these inclusions and exclusions, the Principal Investigator added numerous other items to the glossary on his own authority.

It is of the utmost importance to realize that the definitions given below are restricted to the usage of a word or phrase in this report. The definition of "drift", for example, is peculiar to commercial mussel fishing, will be unfamiliar to most readers, and is not to be found in Webster's! In this instance and many others, alternative definitions are possible.

If the word is a noun or the phrase is nominative, it is given with its plural, plus derived adjectives. If the plural is formed in an unusual way (e.g., in the case of a Latin cognate), it is spelled out in full and parenthesized; if the plural is of ordinary English construction, it is indicated by "(s)". Examples include "glochidium (glochidia), glochidial" and "congener(s), congeneric".

If the word is a verb, it is given in the form of the first person, singular number, and active voice, and any relevant participles follow. An example is "pollywog, pollywogging" (this is another instance of an expression's being defined here in a way likely to be encountered nowhere else).

These formats are not followed completely if a derived word is very rare or does not exist. For examples, "benthos" has a derivative adjective ("benthic"), but no plural, and the adjective "common-name" has little or no use.

The glossary entries are alphabetized without regard to punctuation marks that occur in certain abbreviations; the slash (as in "L/D") and the ampersand ("O & M") are ignored.

Academy--See "ANSP".

anadromous--ascending to continental waters in order to spawn (e.g., *Alosa chrysochloris*, Exhibit 1a). See "catadromous".

ANSP--Academy of Natural Sciences of Philadelphia.

ARCO--Authorized Representative of the Contracting Officer. See "COAR".

arenophile(s), arenophilic, arenophilous--an inhabitant of sand.

baseline study (studies), baseline-study--the original study of a given area, to which later studies can be compared.

benthos, benthic--all organisms living in, on, or very close to a waterway bed.

bivalve(s), bivalve, bivalved--an animal with two, apposing parts of its shell or other outer covering (e.g., exoskeleton). Bivalves occur among crustaceans (water fleas, pill-bugs, crabs, etc.), Bivalvia, and snails.

Bivalvia--a subgroup of the Mollusca in which the shell consists of two apposed parts; clams, mussels, etc.

bone(s), bone--an ancient single valve of a mussel shell. Bones usually are so beaten and/or corroded that they have lost most or all periostracum, are disintegrating rapidly, and are hardly identifiable. See "gaper".

bradytictic--of or pertaining to organisms (notably freshwater mussels) that incubate eggs and/or larvae for a long period, usually including the winter in the Nearctic region.

brail(s), brail--a device for sampling or harvesting freshwater mussels (see Methodology).

catadromous--descending to the sea in order to spawn (e.g., *Anguilla rostrata*, Exhibit 1b). See "anadromous".

centrarchid--of or pertaining to bass and sunfish. See Centrarchidae, Exhibit 1b.

channel maintenance--the collective acts (dredging, riprapping, etc.) that keep the 9-Foot Channel (or any other navigation channel) at its specified depth.

character(s), character--a feature (e.g., a shell) common to an organism and its relatives. See "character-state".

character-state(s), character-state--a variation of a character (e.g., the kind of sculpture on a shell). See "character".

clam(s), clam (*not* clammy)--any member of the Bivalvia. See "mussel".

COAR--Contracting Officer's Authorized Representative. See "ARCO".

COE--See "USACE".

common name(s)--See "vernacular name".

community (communities), community--all members of one or more taxa in a defined area.

conchological--of or pertaining to the shell (as opposed to the soft tissues) of a mollusk.

congener(s), congeneric--one of two or more members of the same genus.

Corps--See "USACE".

Cumberlandian--of or pertaining to freshwater mussels restricted to the Cumberland River drainage and a few neighboring streams, chiefly in eastern Kentucky (see van der Schalie and van der Schalie, 1950). See "Ozarkian".

DNR--Department of Natural Resources.

dredge cut--the exact location where streambed material is removed by dredge.

drift--a continuous series of brail runs (see Methodology and Appendix B).

ecosystem(s), ecosystematic--habitat plus all organisms therein. "Habitat" may be very broadly construed; one thus may speak of a global ecosystem or one far more local (e.g., the UMR ecosystem).

ecotone(s), ecotonal--a mixed, diversified habitat (e.g., the littoral) created by the overlap of adjacent, distinct, simpler habitats.

Endangered Species--Exact definition appears in PL 93-205 ("The Endangered Species Act of 1973") and its amendments. Consult the *Congressional Record* and the *Endangered Species Technical Bulletin*.

English name(s)--See "vernacular name".

ethnomalacologist(s)--one who studies the relationship between mollusks and man, especially early man.

eurytopic--tolerating a wide variety of habitats.

exotic--originating somewhere other than a region where currently found.

fauna (faunae), faunal, faunistic--all animal life in a given area.

fishway(s), fishway--any device that permits mobile (and, especially, migratory) fishes to traverse waterway obstructions in order to complete their normal life cycles (see Clay, 1961, and Eicher, 1970).

fluviatile--of or pertaining to running water, as a river, creek, etc.

food web(s), food-web--the sum of all feeding habits in a community of organisms.

FWS--See "USFWS".

gaper(s), gaper--a pair of old, empty valves of a mussel shell that are still attached by the ligament. See "bone".

genus (genera), generic--one or more uniquely related subgenera or species.

glochidium (glochidia), glochidial--the larval stage in the life cycle of a unionid freshwater mussel. A glochidium is very minute (its dimensions usually are measured in no more than fractions of mm). It has little or no automotive ability and usually must attach to a vertebrate host (almost always a fish) immediately after discharge from the parent mussel.

gravid--pregnant; bearing eggs, larvae, and/or young. A gravid freshwater mussel may have eggs and/or glochidia in the marsupium (see Appendix E).

hermaphrodite(s), hermaphroditic--an organism having both male and female reproductive structures.

hp--horsepower.

ichthyofauna--the fish fauna.

impoundment(s), impounding, impoundment--a stream or reach whose flow has been obstructed, as by a dam.

J/B--johnboat.

juvenile mussel--a mussel from the time it drops off its host after metamorphosis until it is a few years of age. In

this report a mussel also is considered juvenile if it is caught by brail, but not actually on a "hook" (see Methodology).

larva (larvae), larval--the stage that follows the ovum (egg) in the life cycle of a metamorphic animal.

Latin name(s)--See "vernacular name".

L/D--Locks and Dam.

left bank--The left bank of a stream is to the observer's left as he faces downstream; the right bank, to his right.

lentic--of or pertaining to waterways of little or no flow, as lakes, ponds, and backwaters. See "lotic".

limnetic--of or pertaining to fresh water.

limnophile(s), limnophilic, limnophilous--an inhabitant of lentic waters. See "rheophile".

lithophile(s), lithophilic, lithophilous--an inhabitant of rocky areas.

littoral(s), littoral--the part of a waterway bed that lies between the highest and lowest water levels. Littoral is loosely synonymous with the shallows in non-tidal waterways.

lotic--of or pertaining to flowing waterways. See "lentic".

LSAF--Lower St. Anthony Falls (Pool).

malacofauna--the mollusk fauna.

malacology, malacological--the study of mollusks.

metamorphosis (metamorphoses), metamorphic--change, especially in the case of an organism that profoundly alters its structure as it passes from one stage in its life cycle to the next. The egg-larva-juvenile-adult-egg cycle exhibited by unionid mussels is a good example.

mm--millimeter(s).

Mollusca--a phylum (subdivision of the animal kingdom) whose members' soft tissues are more or less protected by a hard shell of one or more parts: chitons, tusk shells, clams (mussels, oysters, etc.), snails, octopuses, etc.

mollusk(s) [mollusc(s) in general United Kingdom usage], mollusk, molluscan--The plural equals Mollusca.

morph(s), morphic--one of the possible forms of a taxon whose appearance is variable.

mussel(s), mussel--any of several groups of elongate clams, notably the Edible or Blue Mussel, a marine species; the Nearctic Unionidae; and other closely related bivalves in continental waters elsewhere. All mussels are clams, but not all clams are mussels. See "clam".

mussel bed(s), mussel-bed--a dense assemblage of mussels.

nacre(s), nacreous--the inner, pearly layer of a unionid mussel shell. The middle, prismatic layer, also, is composed of calcareous compounds. The outer, proteinaceous layer (the periostracum) is somewhat more resistant to the erosive and corrosive stresses of the aquatic environment.

naiad (naiads, naiades), naiad--a freshwater mussel. The same expression is applied to the larvae of certain aquatic insects and to certain aquatic and/or water-associated plants. "Naiad" is not equivalent to "naid", a vernacular name for members of a family of aquatic earthworms.

Nearctic, Nearctic--of or pertaining to the Northern Hemisphere of the New World; i.e., North America above the tropics.

neontologist(s)--one who studies living organisms, as opposed to those that are extinct.

nursery bed(s), nursery-bed--a bed of mussels, usually consisting chiefly of young individuals and located in a backwater from which neighboring areas of streambed (notably the navigation-channel borders) can be colonized by individuals transported as glochidia on fish.

OES--Office of Endangered Species, USFWS, Washington, D.C.

O & M--Operations and Maintenance, a broad category of functions that pertains to federal government agencies, notably the USACE.

OSU--Ohio State University.

Ozarkian--of or pertaining to organisms (notably freshwater mussels) nearly or fully restricted to the Ozark plateau, chiefly in Arkansas and Missouri (see van der Schalie and van der Schalie, 1950). See "Cumberlandian".

parasite(s), parasitic--an organism that is constantly and intimately associated with another organism and feeds upon it. See "symbiont".

parasitism--a symbiosis in which one kind of organism (the parasite) feeds on or in another (the host).

pelagic--of or pertaining to an aquatic organism of any size that depends chiefly upon currents for its movements.

periostracum (periostraca), periostracal--See "nacre".

phalanx (phalanges)--a delicate, leaf-like tubercle in the neoteinic (see Appendix E) sculpture of certain mussels, as *Quadrula quadrula* in the UMR. The phalanges (especially well developed on the immediately post-larval shell) are thought to offer the juvenile animal both stability and buoyancy in streambeds, especially those that consist of finely divided materials.

phylogeny (phylogenies), phylogenetic--the history of the evolution of a taxon.

PL--United States federal Public Law.

plankter (plankters, plankton), planktonic--a microscopic aquatic organism that depends chiefly upon currents for its movements.

pollywog, pollywogging--to collect benthos (notably freshwater mussels) by hand while crawling and/or swimming in shallow water.

pool/Pool(s), pool/Pool--any impoundment caused by the 9-Foot Navigation Channel Project (or any other impounding action). "Pool" is a proper (capitalized) noun when used in conjunction with a number or denomination (e.g., Pool 6, LSAF Pool).

population--all members of a given species-group taxon in a defined area.

Principal Investigator--The Academy assigns one or more Principal Investigators (PI) to each study or project. The responsibility of a PI is to ensure good scientific quality in his area of expertise. The PI for the study reported here was Samuel L. H. Fuller.

reach (reaches), reach--a segment of a stream. A reach comprises the entire breadth of the stream between specified upstream and downstream points.

recruitment--the addition of new individuals to a population.

recruitment level--the quantity of recruitment necessary to ensure that the number of individuals in a population

remains essentially static. A population at or above recruitment level is viable or both viable *and* increasing; one below this level is in decline and headed toward extinction.

relic bed(s)--an isolated bed of very old mussels only.

residual bed--See "relic bed".

rheophile(s), rheophilic, rheophilous--an inhabitant of lotic waters. See "limnophile".

riffle(s), riffle--an occasional, shallow-water reach characterized by a streambed of rocks and gravel and by fast, oxygen-rich water. The unionid mussel genus *Plagiola* (the riffle shells) is a good example of a benthic group that faces extirpation (and even extinction) on account of the ongoing depletion of this habitat.

right bank--See "left bank".

riprap--a thick layer of rocks used to hold soil in place.

RM--river mile(s).

R/V--research vessel.

scientific name(s)--See "vernacular name".

Service--See "USFWS".

species (species), specific--a population of organisms that cannot interbreed enduringly with another population.

species-group--of or pertaining to a species or a subspecies.

spoil--dredged material.

subgenus (subgenera), subgeneric--one or more uniquely related species; a subdivision of a genus.

sybling species--two very similar species, each of which inhabits a different, but neighboring area.

symbiont(s), symbiont, symbiotic--an organism intimately associated with another. See "parasite".

symbiosis (symbioses), symbiotic--an intimate association of two or more kinds of organisms. See "parasitism".

tachytictic--of or pertaining to organisms (notably freshwater mussels) that incubate eggs and/or larvae for a short period, usually the summer in the Nearctic region.

taxon (taxa), taxonomic--a name for one or more related organisms.

taxonomy (taxonomies), taxonomic--the science of naming and classifying organisms.

taxon-specific--related to a given taxon.

Threatened Species--See "Endangered Species".

TVA--Tennessee Valley Authority.

Unionidae, unionid--the taxonomic family of large Nearctic freshwater Bivalvia.

UMR--Upper Mississippi River.

UMRCC--Upper Mississippi River Conservation Committee, currently Rock Island, Illinois.

USACE--United States Army Corps of Engineers.

USAF--Upper St. Anthony Falls (Pool).

USFWS--United States Fish and Wildlife Service.

UWLC--University of Wisconsin at La Crosse.

vagility (vagilities), vagile--an organism's ability to increase its geographic range.

valve(s), valve--one of the apposing halves of the shell of a bivalve.

vascular vegetation--plants having vein-like structures for the movement of fluids.

vernacular names(s)--the English name locally applied to a freshwater mussel (or other organism), as apposed to the scientific name, which is in Latin (see Appendix A).

waterway(s), waterway--any body of water.

WDNR--Wisconsin DNR.

WES--Waterway Experiment Station, Vicksburg District, USACE.

wing dam or wingdam(s), wing dam, wingdam, wing-dam--a structure built of rock and/or woody vegetation and placed more or less perpendicular to the river bank for the purpose of diverting water into the UMR navigation channel in order that it flow deeper and faster. A corresponding result was that main channel borders of the UMR suffered prompt

reorientation of erosion and sedimentation patterns as the behavior of currents quickly altered. Many mussel beds were either swept away or buried. See Grier (1922, 1926a).

xeric--dry.

INDEX

The index is limited to the nomenclature of mussels and mussel symbionts. The vernacular and scientific names of each such organism are listed. The list concerns only the first volume (i.e., text, as opposed to appendices) of this report. In this index the entries appear in alphabetical order, of course, but phylogenetic order is observed in Appendix A.

Sites where the Academy conducted mussel surveys are not included here, but are listed (with page references to their respective discussions) in a tabulation that appears early in each volume. That table also directs the reader to the maps and data portrayals that correspond to each study site.

ADDITIONS AND CORRECTIONS

Page and, as useful, paragraph and line references are given. Enumeration of "paragraph" on a given page starts with the first complete *or* fractional paragraph on that page.

Volume I

Page 11, paragraph 3:

In 1977 D.D. Williams (1978) found what may be another, probably lesser, bed in the St. Croix River at Prescott.

Page 11, paragraph 5, line 7:

For "vascular vegetation" read "submerged vascular vegetation".

Page 12, paragraph 1, lines 4-5; page 118, paragraph 5, line 5:

For "Hudson Railroad Bridge Site" read "Hudson Site".

Page 13, paragraph 2, line 5:

"Fuller (1974b)" in Fuller (1978b) is Fuller (1974) in the present report.

Page 15, paragraph 2; page 73, paragraph 4, lines 5-8:

Elliptio crassidens has been recorded alive from the Prairie du Chien East Channel Site, also (Exhibit 188; Fuller, 1978b).

Page 15, paragraph 4, lines 12-13:

This discussion is somewhat clarified by noting that, while this parasite (possibly these parasites) usually occurs in the mussel's viscera, it has also been observed in the post-basal mantle margin. In such cases it may modify the appearance of the mantle flap and thus inhibit the host's reproductive behavior by damaging the minnow-like flap's ability to lure predatory fishes close enough to the female mussel to be infected with glochidia.

Page 17, paragraph 3, lines 6-7:

Sites cursorily studied in 1977 were reviewed in Fuller (1977, 1978b). Those surveyed in 1978 and 1979 were discussed

by Fuller (1978a, 1979c); most are mentioned in the text of the present report or among the Additions and Corrections below.

Pages 19-20:

There is, unfortunately, no positive correlation between the distribution patterns of fishes (Eddy and Underhill, 1974) and of mussels above the USAF Pool.

Page 20, paragraph 2, lines 16-19:

The point is that current perhaps would be less in sheet meltwater than in a constrained fluviatile watercourse.

Page 22, paragraph 2:

Fuller (1978b, 1979b) is the source of the remark about the Des Moines River's having an adverse impact upon the UMR.

Page 29, paragraph 1-4:

Amblema plicata, not *Fusconaia flava* is the dominant mussel in the St. Croix River. This correction must be taken into consideration in interpreting the St. Croix influence upon the UMR.

Page 29, paragraph 4:

The Diamond Bluff Site had been cursorily surveyed earlier in 1978 (Fuller, 1978a).

Page 29, paragraph 5:

For "Trenton Site that" read "Trenton Site, which".

Page 34, paragraph 1, line 7 (and elsewhere in the report):

For "P. Thiel" read P.A. Thiel".

Page 38, paragraph 1, line 10:

The "study area" in question consists of the sites surveyed, as opposed to the entire UMR reach under study (see Methodology).

Page 41, West Newton:

A subsequent, cursory survey of part of this Site produced no new information (Fuller, 1978a).

Page 42, paragraph 1, line 3:

"Fuller (1977a)" in Fuller (1978b) is Fuller (1977) in the present report.

Page 43, paragraph 4:

A cursory survey of part of the Island 58 Site earlier in 1978 had produced nothing to change the present account (Fuller, 1978a).

Page 44, paragraph 1:

Cursory surveys of parts of the Betsy Slough and Wilds Bend Sites early in 1978 had produced no living mussels (Fuller, 1978a).

Page 45, Winona Lower Railroad Bridge:

To this account should be added the following paragraph:

It was near this site that the Winona nursery beds were found. Opposite Winona and abutting upon (and perhaps including waterlots owned by) the Delta Fish and Fur Farm, there are extensive shallow-water areas that proved to be unusually productive nursery grounds for mussels (and, presumably, their host fishes). Partly in order to gather mussel bioassay materials for the Corps Waterways Experiment Station in the Vicksburg (Mississippi) District (see Peddicord et al., 1979), the Academy investigated these shallows extensively. The rich mussel fauna of these beds far exceeded expectations based on experience of the Twin Cities and Chippewa Zones of naiad life. These beds are especially notable for their great abundance of juveniles and immediately post-larval individuals (some of which have been used as figured specimens in the taxonomic key to UMR mussels, Appendix E). These beds not only have provided insight into the UMR biologies (sometimes enigmatic) of certain mussel species, but also have provided new information about the success of certain species much farther upriver than had been suspected. Species of especial interest in this context include the Threehorn (*Obliquaria reflexa*) and the Mapleleaf (*Quadrula quadrula*).

Page 45, paragraph 6, line 6:

The Gravel Point Site living specimen of *Fusconaia ebena* actually is *almost* the "only" recent UMR record in the St. Paul District (Mathiak, 1979).

Page 47, paragraph 1, lines 3-5:

Delete "This is the northernmost 1978 Site at which this classic UMR domination of the mussel fauna was apparent".

Page 47, paragraph 3, line 7:

For "uppermost" read "northernmost".

Page 49, paragraph 6, line 5:

To the end of this account should be added the following sentence: "Like the Sand Slough and Root River Sites (just above), this one probably suffers from an unidentified adverse impact."

Page 51, paragraph 3, lines 8-9 (and elsewhere in this report):

Note, however, that *Quadrula nodulata* is *natively* a southern element in the UMR fauna.

Page 51, paragraph 5, line 3:

"Perry (1978)" in Fuller (1978b) is Perry (1979) in the present report.

Page 53, Indian Camp Light:

The recent dredging history at this Site disputes the contention that dredging "could hardly have been at fault", but nevertheless is insufficient to explain the "exceptionally poor" mussel fauna.

Page 53, Lansing Small Boat Harbor:

This Site obviously gains nothing from its proximity to the Whiskey Rock mussel bed below Lansing.

Page 56, paragraph 1:

Note that only *part* of the Opposite Harpers Slough Site was surveyed; the Academy did not formally study this site.

Page 57, paragraph 3:

To the end of this paragraph should be added the following observations: "This assemblage is typical of the UMR on account of its domination by *Amblema plicata*, but the number and variety of its species, plus the abundance of many, certainly are not typical. The Academy's data (Exhibit 188) convey an only superficial sense of the richness of these populations and this community."

Page 57, paragraph 5:

Note that (1) important additional support of the workshop was provided by UWLC and WDNR and that (2) the mussel data generated by the workshop truly are "reflected" (but are not included) in the present report (i.e., Exhibit 188).

Page 58, paragraph 2:

Note that the McGregor waterfront surveillance was conducted on the Academy crew's personal time, and with the full knowledge of the Government (USACE and USFWS).

Page 59, paragraph 1:

During August (1980) the St. Paul District mussel survey crew found a living *Lampsilis higginsi* near the McMillan Island Site (R.J. Whiting, personal communication).

Page 63, paragraph 2:

Note that most 1978 and 1979 field work was conducted outside the known recent range of *Megalonaias gigantea* in the UMR, St. Paul District, but that only at Prairie du Chien is this species at all numerous.

Page 68, paragraph 2, line 2 (and elsewhere in this report):

Lake Keokuk is not equivalent to Pool 19; instead, it occupies the lower portion of that Pool.

Page 68, paragraph 3, lines 8-9; page 119, paragraph 4, lines 6-7:

The proposal to list *Cumberlandia monodanta* as a nationally Threatened Species has been withdrawn.

Page 70, paragraph 4:

Tritogonia verrucosa recently was taken alive from the lower Black River (Havlik, 1978a).

Page 72, paragraph 1:

In a recent study of Pool 20, Heffelfinger (1973) found that concentrations of natural aquatic chemical constituents had changed very little during previous decades. Therefore, the Skipjack Herring and the Ebony Shell should be able to penetrate the UMR as far upstream as Locks and Dam 19. Their failure to penetrate this far is probably due to unnatural substances in the River.

Page 75, paragraph 1, lines 5-10:

About 20 years ago *Plagiola lineolata* was found alive in Lake Pepin, Pool 4 (Morrison, 1959).

Page 75, paragraph 3:

It should be emphasized here that *Leptodea leptodon* probably faces extirpation from (if it is not already extirpated from) the UMR.

Page 78, paragraph 4, lines 1-2:

Grier and Mueller (1922-1923) recorded *Ligumia subrostrata* from Fountain City, Wisconsin, in Pool 5A; Grier (1922), recorded this mussel above Homer, Pool 6.

Page 79, paragraph 4; page 80, paragraph 1, line 1; page 149, Endangered Species:

Modifications of PL 93-205 are PL 94-325 and -359 (both 1976), PL 95-212 (1977), PL 95-632 (1978), and PL 96-159. The last two are better known as "The Endangered Species Act Amendments of 1978" and "The Endangered Species Act Amendments of 1979", respectively.

Page 80, paragraph 1; page 114, paragraph 1, lines 9-11:

In 1979 and 1980 the WDNR survey occasionally found stray Higgins' Eye that certainly were *not* in mussel beds (P.A. Thiel, WDNR, LaCrosse, personal communication).

Page 81, paragraph 3:

Note that the Carp is an exotic, Eurasian fish and that *Lasmigona costata* doubtless uses native host fish(es), which have not been identified as such.

Page 83, paragraph 1, lines 1-2:

Recent discoveries of *Anodonta suborbiculata* in Pools 9 and 10 (M.E. Havlik, Malacological Consultants, LaCrosse, Wisconsin, personal communication) support the theory (Fuller, 1978b) that this species is gradually extending its UMR range.

Page 83, paragraph 5:

Mussels' redundant use of certain fishes (e.g., Sauger, Freshwater Drum) as glochidial hosts militates somewhat against the idea that host selection is the (or a) key to resource partitioning by mussels. On the other hand, in spite of the seeming wealth of relevant information (see Fuller, 1974, 1978b,

plus additional data reviewed in the present report), there is a general paucity of knowledge about most mussels' hosts. Moreover, Sauger and Drum are probably prevalent in known host-parasite correlations largely because they have been easy to study.

Page 90, paragraph 4:

Corbicula fluminea has recently been found living in Pools 13-15 (J.R. Brice, Hazleton Environmental Services Corporation, Northbrook, Illinois, personal communication).

Page 92, paragraph 2:

T.O. Claflin (UWLC, personal communication) cautioned against the automatic assumption that these three stages in the early biotic development of a deep reservoir can be imputed to a shallow river-lake. For example, argued Dr. Claflin persuasively, the nutrient pulse in stage one is apt to be minor where (as probably was the case in the UMR valley) the permanently inundated ground had perennially been flooded; these regular floods had long since leached many of the nutrients from the lowland soil.

Page 92, paragraph 4:

Dr. Claflin suggested that loss of macrophytes in impounded shallows of the UMR because of accumulation of unstable sediments now is far less common then macrophytic invasion of shallows. This situation probably favors mussels as long as it is not an aspect of utterly lentic waters.

Page 95, paragraph 2:

Note that Corps activities (channel maintenance and some construction) are by far the majority of UMR dredging in the St. Paul District.

Page 102, paragraphs 3 and 5:

T.O. Claflin further cautioned that, once Lake Pepin is saturated by pollutants, the downstream UMR will, in effect, join the Twin Cities Zone. Therefore, Recommendation 3 (p. 114) should emphatically be applied to the Chippewa and Recovery Zones, as well.

Page 104, paragraph 3, lines 4-5:

Parker (1979) conclusively demonstrated an instance of hypertachytixis, in *Glebula rotundata* (Lamarck).

Page 110, paragraph 1:

The point is that disturbance by dredging activities (or any other unnatural physical contact) can make gravid females abort.

Page 119, paragraph 4, lines 10-11; page 122, paragraph 2, line 5:

Actual Academy encounters with living Higgins' Eye should be clarified. The Academy crew found living *Lampsilis higginsi* at the Hudson and Prairie du Chien East Channel Sites and examined animals taken alive by commercial clammers from the Whiskey Rock bed below Lansing, Iowa. A freshly killed specimen was taken in 1977 from a "spoil bank" at Brownsville, Minnesota, though not by Academy personnel. During the study period the Principal Investigator had occasion to examine living *L. higginsi* taken by other investigators, notably the WDNR. The WDNR also found numerous living Higgins' Eye at and near Prairie du Chien during the summer of 1980, and the Corps found one near McMillan Island in August. A grand total of about two-score animals thus has been found in the St. Paul District since 1977, but the Academy had little to do with most of these discoveries.

Pages 125-146:

The foloowing citations should be added to the Bibliography section:

Ackerman, G.L. 1976. Survey of freshwater mussels of the upper Mississippi River. Upper Mississippi River Conservation Committee, Davenport, Iowa. 9 Pp.

Davis, G.M., and Fuller, S.L.H. 1980. [A new classification of Nearctic Unionidae.] Malacologia. In press.

Ellis, M.M. 1941. Freshwater impoundments. Transactions of the American Fisheries Society, 71:80-93.

Fuller, S.L.H. 1979b. Letter of 15 May 1979 to K. Price. 5 Pp.

Isom, B.G. 1971. Effects of storage and mainstream reservoirs on benthic macroinvertebrates in the Tennessee Valley. Pp. 179-191 *In*: Hall, G.E., editor, Reservoir Fisheries and Limnology. American Fisheries Society Special Publication No. 8:1-511.

Jorgensen, S.E., and Sharp, R.W., editors. 1971. Proceedings of a symposium on rare and endangered mollusks (naiades) of the U.S. United States Department of the Interior, Fish and Wildlife Service Bureau of Sport Fisheries and Wildlife, Washington, DC Pp 1-79.

Morishita, I. 1973. Benthonic animal types of the dammed lakes in Japan. Japanese Journal of Limnology, 34:192-201.

Oesch, R.D. 1981. The naiades of Missouri. Missouri Department of Conservation, Jefferson City. In press.

Pennak, R.W. 1978. Fresh-water invertebrates of the United States. Second edition. Wiley, New York. Pp. 1-803.

Pages 125-126:

"Armitage, et al. (1974)" (p. 125) should appear after "Armitage (1977b)" (p. 126).

Page 125:

The Elliot (1973) and Obeng (1973) papers cited in the text appear in Ackermann (1973).

Page 127 (and elsewhere in Bibliography):

"ASB" stands for "The Association of Southeastern Biologists" in the citation of Bereza et al. (1976) and in the following works: Fuller (1971), Howe (1980), Parker et al. (1980), Ritchie et al. (1980), Webb and Dennis (1980), and Zeto (1980).

Page 127:

For "Boss, K.J., Rosewater, J." read "Boss, K.J., Rosewater, J., and Ruhoff, F.A.".

Pages 128 and 130:

In the citations of Cowley (1977) (p. 128) and "Davis and Cawley (1975)" (p. 130), for "E.T. Cawley" read "Loras College".

Page 133:

To the citation of "Fuller (1980b)" add "*In*: Rasmussen, J.L., editor. Report of the Thirty-seventh Annual Meeting of the Upper Mississippi River Conservation Committee. Rock Island, Illinois".

AD-A097 002 ACADEMY OF NATURAL SCIENCES OF PHILADELPHIA PA DIV OF--ETC F/G 6/6
FRESHWATER MUSSELS (MOLLUSCA: BIVALVIA: UNIONIDAE) OF THE UPPER--ETC(U)
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To the citation of "Gale (1969)" add "Subsequently distributed by University Microfilms Internation, Ann Arbor and London, as publication 69-20,642."

In the citation of "Garman, 1888", for "Bull. Ill. St. Lab. Nat. Hist." read "Bulletin of the Illinois State Laboratory of Natural History".

Page 139:

In the citations National Biocentric (1979a, 1979b, 1979c), for "St. Paul, MN" read "St. Paul, Minnesota".

In the citation National Biocentric (1979d), "CSAH" stands for "County State Aid Highway".

Page 142:

In the citation Shira (1913), for "Economic Circular" read "Department of Commerce Economic Circular".

Pages 147-15 :

The following entries should be added to the Glossary section:

♀ -- the universal symbol for the female.

artificial -- unnatural, convenient, as in an artificial classification (e.g., Exhibit 1b, in part) or taxonomic key (e.g., Appendix E). See "natural".

asphyxiation -- death caused by oxygen deprivation.

bioassay(s) -- investigation(s) of the effect of a substance on an organism.

biomass -- the total quantity (usually expressed as weight) of living matter in a specified group of organisms.

byssus (byssi), byssal -- the thread or threads with which a juvenile unionid mussel anchors itself to stable substrate.

charged marsupium -- the marsupium when nearly or quite full of eggs and/or glochidia. See "glochidium" and "marsupium".

climax(es) -- the final stage in the development of a community of organisms.

conchologist -- one who studies shells of mollusks.

conchology -- the study or science of molluscan shells. See "malacology".

couplet -- one of two or more pairs of mutually exclusive choices in a taxonomic key (e.g., Appendix E).

couplet - choice -- one of the two choices in a couplet.

DO, D.O. -- dissolved oxygen.

drawdown -- a purposeful lowering of water level.

EIS -- environmental impact statement.

eutrophication -- an increase in organic nutrients leading to increases in populations and often in their community.

excyst -- to leave a cyst, as a juvenile mussel when it drops from its host fish.

extinct -- of or pertaining to a taxon all of whose members are dead.

extinguish -- to render extinct. See "extirpate".

extripate -- to drive out or kill off locally, not throughout a taxon's entire geographic range. See "extinguish".

extralimital -- of or pertaining to a taxon at the edge of its geographical and/or ecological range, i.e., a taxon whose best development occurs somewhere other than the area under study.

facultative -- not obligatory.

fall line -- a continuous land promontory that causes falls in adjoining rivers.

fetch -- the distance traveled, as by wind over water. If the fetch is great enough, turbulent surface water (e.g., waves) may result.

fixation -- the hardening of soft tissue, as by formalin.

gonad -- an organ for producing ova or sperms.

mantle -- the tissue that cloaks the body of a mollusk and lines the inside of the shell (if present).

mantle sheet -- the molluscan mantle within its margins.

MNDOT -- Minnesota Department of Transportation.

MR -- Mississippi River.

naiadology -- the study or science of freshwater mussels.

natural - in phylogenetic order, as a classification, list or taxonomic key. See "artificial".

overbank -- of or pertaining to aquatic habitat created by permanent lowland flooding during impoundment.

ovum (ova), oval, oviform -- egg.

pisciform -- in the form of a fish.

planktivore -- an organism that feeds on plankton.

quadrulae -- two or more members of the genus *Quadrula* (see Exhibit 1a).

RR -- railroad.

sub -- a prefix meaning almost, approximately, and/or smaller than.

subfossil -- of or pertaining to biological remains (ususally bones or shells) that are not yet fully mineralized; a very old empty mussel shell. See "bone".

trematodiasis -- disease caused by infestation with flukes, a group of parasitic flatworms (Platyhelminthes: Trematoda).

UM -- Upper Mississippi.

Unionicolidae, unionicolid -- the family of water-mites that are symbiotic (usually as parasites) in freshwater mussels.

USEPA -- United States Environmental Protection Agency.

vector(s), vector -- an organism that serves to spread another organism.

white water(s) white-water -- turbulent, usually foaming water, as in rapids.

zoogeographic -- of or pertaining to the geographic distribution of animals.

Page 155, unionidae:

The unionidae further should be distinguished from the only other characteristically freshwater families of Nearctic bivalves: Corbiculidae (sole representative: the exotic *Corbicula fluminea* (Müller), the Asiatic Clam) and Sphaeriidae (pill, pea, and fingernail clams). These families do not exhibit a nacreous layer in their shells.

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